PB86-221173

Effectiveness of Nonstructural Agricultural Best Management Practices (BMP's) for the Control of Phosphorus and Nitrogen

Viking Systems International, Inc., Reston, VA

Prepared for

Environmental Protection Agency, Washington, DC

Jul 86

U.S. Department of Commerce
National Technical Information Service
NTIS

50272-101 EPA-230-10-86-020

REPORT DOCUMENTATION PAGE	**1. REPORT NO.** EPA-230-10-86-020	**2.**	**3. Recipient's Accession No.**

4. Title and Subtitle
Effectiveness of Nonstructural Agricultural Best Management Practices (BMP's) for the Control of Phosphorus and Nitrogen

5. Report Date
7/86

6.

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8. Performing Organization Rept. No.
DCN# E85062

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10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) SDA3-85-4049
(G)

12. Sponsoring Organization Name and Address
EPA
401 M Street, S.W.
Washington, D.C. 20460

13. Type of Report & Period Covered
Final

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

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17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement: Unlimited	**19. Security Class (This Report)** Unclassified	**21. No. of Pages** 133
	20. Security Class (This Page) Unclassified	**22. Price**

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

PB86-221173

EFFECTIVENESS OF NONSTRUCTURAL AGRICULTURAL BEST MANAGEMENT PRACTICES (BMP's) FOR THE CONTROL OF PHOSPHORUS AND NITROGEN

VIKING SYSTEMS INTERNATIONAL
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REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

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(Final Report)

PURCHASE ORDER NO. DCN# E85062
CONTRACT NO. SDA3-85-4049

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TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	1
1.0 INTRODUCTION	7
1.1 Scope of this Report	9
2.0 SEDIMENTS AND NUTRIENTS IN RUNOFF	11
2.1 Nature and Role of Sediments	11
2.2 The Erosion/Sedimentation Process	15
2.3 General Nature of Nutrient Transformation	23
2.4 Phosphorus -- Its role, Movement, and Transformation	25
2.5 Transport and Fate of Nitrogen	43
2.6 Nutrient Lag Time	53
3.0 AGRICULTURAL BEST MANAGEMENT PRACTICES	58
3.1 Conservation Tillage	63
3.2 Contour Farming	72
3.3 Cover Crops	75
3.4 Crop Rotation	77
3.5 Tree Barriers	81
3.6 Comparative Assessment of Various BMP's	85
4.0 BMP'S OPTIMIZATION AND EFFECTIVENESS	87
4.1 Systems Optimization	88
4.2 Watershed Approach	90
5.0 CONCLUSIONS AND RECOMMENDATIONS	96
5.1 Future Research Needs	99
6.0 REFERENCES	101

Page

APPENDICES

Tables

1. Estimated Sediment, Nitrogen, and Phosphorus Contributions From Selected Nonpoint Sources in Contiguous 48 States. 13

2. Impacted Waters. 14

3. Rural Clean Water Projects 22

4. Crop Management Methods. 60

5. Effect of Crop Sequence and Duration of Sod Crop in Crop Rotation on Infiltration and Soil Loss From a Loam Soil With 5 Percent Slope. 79

Figures

1. Different Forms of Phosphorus. 28A

2. Phosphorus Transport In Runoff. 33A

3. Particulate and Dissolved Nitrogen In Soils and Sediments. 43A

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EXECUTIVE SUMMARY

Runoff from agricultural land is among the leading causes of nonpoint pollution. Such runoff is known to carry suspended solids, nutrients, pesticides and organic carbon. Most nonpoint source pollutant loadings to water bodies are intermittent due to their relationship to storm events. Research suggests that lakes, reservoirs, and estuaries, (such as Chesapeake Bay) are particularly vulnerable to nonpoint contamination. The Chesapeake Bay study indicated that nonpoint source runoff from cropland is currently responsible for the greatest amount of nutrient load to the Bay. Nonpoint sources contribute approximately 67 percent of nitrogen and 39 percent of the phosphorus load to the Bay (Macknis, 1984).

Though steady progress toward clean water goals has been made since passage of the 1972 amendments to the Federal Water Pollution Control Act (FWPCA), the magnitude, constant threat, and persistence of nonpoint water contamination are significant.

In 1984, the U.S. Environmental Protection Agency (EPA) reported to Congress that six out of the ten EPA regions found nonpoint sources to be the principle cause of water quality problems. "Recent national reports have also identified nonpoint source (NPS) pollution as a major remaining water quality problem that will prevent achievement of established water quality goals in priority waters, even when applicable point source controls have been fully implemented". (ASIWPCA, 1986).

Best Management Practices (BMP's) are some of the available, effective and economical methods for controlling nonpoint pollution. However, there is a lack of information on the role and effectiveness of agricultural BMP's in reducing nutrient and sediment in nonpoint runoff. This study assesses the effectiveness of five agricultural BMP's: conservation tillage, contour farming, cover crops, crop rotation, and tree barriers. It examines a subset of issues and questions related to phosphorus, nitrogen and sediment control in agricultural runoff. A "watershed approach" to BMP planning and implementation for "systems" of BMP to work is briefly discussed. The study is a part of EPA's on-going efforts to develop innovative approaches to reducing the cost of achieving environmental and water quality objectives.

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The literature establishes conservation tillage systems as the most cost-effective, widely applicable agricultural BMP for reducing contaminant loads from agricultural runoff. Conservation tillage, which leaves some or all of the residue from the previous year's crop on the soil surface, effectively protects the soil against erosion. It reduces runoff volumes as well as sediment and nutrient losses. Crop yields with conservation tillage are generally higher than yields obtained with conventional tillage during dry seasons, though they are somewhat lower during excessively wet years. As a nationwide BMP, the major potential limitation of conservation tillage relates to effects from increased use of pesticides, which are not clearly understood.

All other BMP's assessed have significant site specific limitations. Contour farming is limited to gentle slopes (8 percent or less) and is more effective on well-drained soils and in areas of abundant rainfall. The use of cover crops reduces erosion more than runoff and is most effective with other runoff reducing practices, (i.e. conservation tillage and contouring). Rotating a sod crop with a row crop also results in reduced soil loss. However, crop rotation alone may be uneconomical unless a cash crop can be included in the rotation. In many soils and numerous geographical regions such an inclusion may not be possible. Crop rotation and conservation tillage, particularly "no-till", may reduce runoff surface nitrogen losses by 40 to 85 percent, as compared to conventional tillage practices. Crop rotations, cover crops, and conservation tillage, on the other hand, can reduce phosphorus losses by 40 to 70 percent, compared to conventional cropping and tillage practices. For phosphorus control, all these BMP's can be widely recommended.

Tree barriers primarily act by reducing wind velocity. However, there is paucity of information on effectiveness of tree barriers as an agricultural BMP.

Since fertilizer is a major component of agricultural runoff, other management practices, particularly proper irrigation and fertilizer management -- matching applications, timing and fertilizer forms with crop needs -- can also bring economical and noticeable water quality improvements.

Sediment affects more river miles than any other pollutant, and is a key contributor of nutrients and toxics. In controlling nonpoint source pollution, the question of sediment transport must therefore be carefully considered. Does this material take many years to move out of a watershed with subsequent scouring and deposition in temporary sinks--swales, ditches and stream bottoms? Or

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does the majority of material observed in passage from a basin during a storm event originate on the land surface during that storm? These questions weigh heavily on the selection of suitable land management techniques. The length of time sediment is in transport is a key determinant of the time required to measure any success achieved by such alternatives as fertilizer reductions.

Nitrogen and phosphorus pollution from a watershed can be effectively reduced by treating the "hot spots" in watersheds rather than applying identical control measures over broad areas of land. These "hot spots" can be identified by means of statistical models such as "ANSWERS". Selection of BMP's can be made by use of Universal Soil Loss Equation (USLE), best professional judgment, and the computer based Land Resource Inventory System (LRIS).

Due to a large number of interacting factors, no single BMP can effectively control all potential agricultural pollutants under all field situations. Even the best available matrix mathematics cannot quantitatively evaluate all factors involved for all possible field conditions. Among the myriad of complex and interacting factors are climatic, geologic, agricultural, physical, chemical, and biological processes that affect pollutant transport and transformation within a watershed. Thus, a system's approach to BMP selection and utilization must be developed. For effective implementation of various BMP's, a watershed approach needs to be adopted. Perhaps the greatest overall need is a series of watershed studies, each with a holistic approach: surface and subsurface water quality, economics, agronomic concerns, and institutional matters.

The most appropriate BMP's for a particular problem need not be determined through an optimization process, but feedback between water quality effects and control alternatives is obviously desirable. Given the difficulties of maximizing water quality under management constraints, a reasonable procedure may be to establish the water quality constraints and then explore possible management strategies to achieve the chosen goals. This might be done by developing a series of scenarios, each consisting of a spatially detailed set of management practices that are shown by "modeling" to yield acceptable pollutant loading. Rather than choosing a "best" plan according to formal criteria, the scenario could be submitted to policymakers, who could examine the products of vigorous analysis and apply intuitive judgment. The judgment and acceptance by the farmer must also come into play in exercising BMP's for nonpoint pollution control.

To evaluate the relative cost-effectiveness of point and nonpoint BMPs, a staged approach, whereby each program builds upon the previous one, can allow for an incremental

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control strategy. The most cost-effective practice is identified, the projected load reduction calculated and applied to some target load reduction. Next the second most cost-effective practice is identified and the project load reduction calculated and so on until the target load is achieved. Alternatively, one practice (such as an agricultural BMP), as the primary practice can be chosen and other BMPs screened to meet required pollutant load reductions.

The effects of even large scale adoption of BMP's will not be seen at the watershed levels in periods less than 5-10 years. Data from some of the Rural Clean Water Programs (RCWP's), Model Implementation Plans (MIP's) and other projects will allow a more refined evaluation of the feasibility and cost-effectiveness of the BMP's though much work will remain before agricultural BMP's can be widely recommended for the control of nitrogen (N), phosphorus (P), and sediments in agricultural runoff.

Conclusions and recommendations regarding "Best Management Practices" for controlling sediment, N, and P in runoff from agricultural lands include:

o Erosion reduction on cropland is generally proportional to reductions in the amount of tillage performed. Conservation tillage systems can reduce soil losses from 60-90 percent compared to conventional tillage and are an effective alternative where no-till is not well adopted. Surface runoff from conservation tillage averages about 25 percent less than conventionally tilled fields.

o Conservation tillage systems will generally give higher crop yields relative to conventional tillage systems on well-drained soils or in dry years. This trend is reversed for poorly drained soils or excessively wet years.

o No-till is extremely effective in reducing erosion losses with reduction of 70-99 percent but is not adapted to all regions and requires higher management than conventional tillage.

o Since 48 to 98 percent of nitrogen and 87 to 99.6 percent of phosphorus in surface runoff is bound to sediment, sediment control practices can reduce the input of N and P from nonpoint sources.

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- No-till can significantly decrease soil losses on land previously under conventional tillage. However, while total particulate P will be greatly reduced, dissolved P due to lesser sediments in the runoff may even increase. Other reasons for higher P levels with no-till are the build up of fertilizer P on no-till soils and the leaching of dissolved P from decaying plant residues. Under such conditions, other management practices particularly proper fertilizer use for controlling dissolved P may be more useful.

- Contour farming reduces runoff and sediment loads by 15 to 55 percent and 40 to 60 percent respectively. Soluble N and P losses are reduced by 15-55 percent. However, reduction in total P loss may not be comparable to reduction in sediment load. This is because the portion of soil lost through erosion as sediment has a higher content of phosphorus as compared to P content of soil in the field.

- Sod-row crop rotations can reduce erosion 80 percent in sod crop years and provide carry over effects when row crops are planted.

- Cover crops reduce nitrogen and phosphorus loss by reducing soil erosion by 40-95 percent. Non-legume cover crops, due to their utilization of nitrogen for plant growth, reduce nitrate leaching to groundwater.

- Although few data are available, it appears that tree barriers or stream side vegetation, improve water quality by lowering the temperature of water in streams. These lower temperatures reduce bio-available phosphorus and nitrogen, because slight increases in stream water temperatures above 15°C produce substantial increase in the amount of P released. Streamside vegetation also reduces the sediment load by protecting the soil from rain drop impact, by entrapping suspended sediments, and by reducing stream bank erosion.

- On sandy soil, relatively small amounts of water have been shown to move nitrates below the root zone which emphasizes that N

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applications should be timed with crop uptake. Use of row crops in rotation with crops such as in oats, and meadow, prevents accumulation of nitrates in the soil solution even at high application rates of 300 pounds of N per acre. Late season application of nitrogen in ammonical rather than nitrate form reduces movement of nitrogen from land to water bodies.

- The use of crop rotations, no-till and conservation tillage may reduce surface N losses by 40-85 percent as compared to conventional practices. Sod based rotations significantly reduce losses of soluble N in surface runoff.
- Fertilizer management practices such as deep placement, incorporation of slow release (nitrogen) fertilizers, and fertility management can effectively reduce N losses to surface and ground waters and P accumulation in upper soil profile and being susceptible to erosion.

While the technology obviously exists for reducing sediment and nutrients in agricultural runoff, development of implementation programs will require consideration of economic realities, production concerns, technical and institutional limitations -- most of which are site specific. Thus, appropriate caveats must accompany any inferences drawn from this study.

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1.0 INTRODUCTION

Nonpoint source pollution remains one of the nation's major water quality problems 14 years after passage of the Federal Water Pollution Control Act of 1972 (P.L. 92-500) and its various amendments, in spite of continuing efforts to improve water quality. Among the various nonpoint pollution sources, agricultural runoff is the most pervasive and the leading cause of water quality problems. Runoff from cropland is the major contributor of sediments and nutrients, that degrade streams, lakes, reservoir and estuaries.

EPA's 1984 report to Congress (US EPA, 1984) indicated that six of the ten EPA regions, serving more than half the states, have shown that nonpoint sources are their major remaining cause of water pollution problems. Virtually every state has expressed concern and reported major water quality problems related to nonpoint sources. More recently, the Association of State and Interstate Water Pollution Control Administrators (ASIWPCA, 1986), indicated that nonpoint contamination has affected drinking water in 22 states, (estimated population: 2.1 million people). In addition, 117,000 miles of the rivers studied were found to be moderately to severely impaired by nonpoint pollution, with another 48,000 miles distinctly threatened. Some 4.4 million lake acres are classified as impaired to varying degrees, and 3.7 million more acres are threatened.

Among the estuaries examined, 2,400 square miles were rated as moderately or severely impaired, with another 3,000 square miles threatened. Conspicuous examples include Chesapeake Bay, where nonpoint sources contribute approximately 67 percent of nitrogen and 39 percent of the phosphorus load to the Bay (Macknis, 1984).

"Best Management Practices" (BMP's) are among the measures available for controlling nonpoint pollution, and "Best Cropping Practices" are among the agricultural BMP's that minimize the amounts of sediments and nutrients lost from croplands that enter water resources. These practices reduce nutrient losses by controlling runoff, and thereby retain nutrients in the crops themselves or in the soil near where they were applied.

Serious as the water quality and environmental impacts of not using BMP's on agricultural lands are, the economic impacts are even more serious, causing an appreciable drain on the nation's economy. These damages include both on-site and off-site. They are associated with pollutants, mainly sediments and nutrients from agricultural runoff. Recent studies indicate that off-site impacts of erosion cost the Nation an estimated $6 billion a year, with over $2 billion accounted for by cropland erosion alone (U.S. E.P.A., 1985).

It would seem a sound, cost-effective policy to attack the source of the problem rather than suffering environmental deterioration and annual loss of billions of

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dollars, year after year. EPA is examining among the various control measures, a number of nonstructural BMP's, to assess effectiveness in reducing nutrient loss from agriculture land and improving water quality. This project is a part of EPA's overall and continuing efforts to meet the nation's water quality goals.

1.1 SCOPE OF THIS REPORT

A review of the available published literature shows that little information on NPS water pollution and agricultural BMP's exists and much research remains necessary. Under a recent EPA contract, "Development Planning and Research Associates, Inc., (DPRA), of Manhattan, Kansas, evaluated the cost-effectiveness of "Best Management Practices and Public Owned Treatment Works in Controlling Phosphorus Pollution." DPRA's study reviewed recent published literature and estimated the cost-effectiveness of various agricultural BMP's, including conservation tillage and contour farming and grassed waterways. The present study, performed under a contract with EPA's Regulatory Reform Staff, complements DPRA's efforts and evaluates five agricultural BMP's (i.e., conservation tillage, contour farming, crop rotation, cover crops, and tree barriers) for their effectiveness in nutrient and sediment control, with the following main objectives:

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- review the literature to assess the effectiveness of nonstructural, agricultural BMP's in reducing phosphorus and nitrogen in the runoff.
- assess the relationship between sediment and phosphorus and sediment and nitrogen.
- assess the phenomenon of "lag time", the period between installation of BMP's and eventual observed improvement of water quality.
- evaluate the effectiveness of combinations of BMP's, developing a "systems approach" to reducing nutrients in the runoff.
- identify the data gaps, if any.

2.0 SEDIMENTS AND NUTRIENTS IN RUNOFF

Sediments and nutrients are major contributors to nonpoint source pollution. Sediments affect more river miles than any other pollutant. In addition, in most instances, the bulk of nutrient loads, particularly phosphates to lakes, is from land drainage, and includes varying proportions of sediment-bound P and dissolved P. Sediment is also an important consideration in control of toxics such as heavy metals or pesticides since it may transport these into aquatic environment. Thus, sediments and nutrients, both individually and collectively in the runoff, have the potential to lead to a significant deterioration in water quality.

2.1 Nature and Role Of Sediments

Sediment from soil erosion has been considered the greatest single pollutant in surface water (Stewart et al. 1975). Other pollutants, such as nutrients, pesticides, and bacteria may be adsorbed on sediments and transported into waterways. Nutrients and pesticides occur in highest concentrations on the small sediment particles because of their large ratio of surface area to volume. Unfortunately, the smaller particles are the most easily eroded and adsorbed pollutants are preferentially removed from croplands. Much of the sediment entering the surface waters in the United States originates from croplands (Table 1).

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The relationship between increased cropping activities and subsequent potential deterioration of surface water quality is generally recognized. During the past decade, conversion of marginal land to cropland, coupled with the advent of "Industrial Agriculture" and a general shift to row crops has resulted in overall increases in sediments and nutrients, and deterioration of water quality attributable to agriculture. According to EPA's 1977 National Water Quality Inventory, agricultural nonpoint sources significantly affected water quality in 68 percent of all drainage basins in the U.S. More recently, the Association of State and Interstate Water Pollution Control Administrators (ASIWPCA, 1986) reported that 42 percent of the nation's streams and 41 percent of the lakes due to impaired water quality primarily due to nonpoint pollution prevent designated water uses (Table 2).

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Table 1. Estimated Sediment, Nitrogen, and Phosphorus Contributions From Selected Nonpoint Sources in Contiguous 48 States (a) (Average Pollution Loads in Million Tons per Year)*

Nonpoint source	Sediment	Nitrogen	Phosphorus
Cropland	1,870	4.3	1.56
Pasture, Rangeland	1,220	2.5	1.08
Forest	256	0.39	0.089
Construction	197	----	----
Mining	59	----	----
Urban Runoff	20	0.15	0.019
Rural Roadways(b)	2	0.0005	0.001
Small Feedlots	2	0.17	0.032
Subtotal:	3,626	7.4	2.8
Natural Background	1,260	2.5	1.1
Total:	4,886	10.0	3.8

Notes: (a) 83.8 million hectares (207 million acres) in public lands (14% of contiguous United States), mostly Rocky Mountain region, is excluded due to inadequacy of information.

(b) Mostly deposition from traffic-related sources.

* Source: Bailey and Waddell, 1979.

Table 2. Impacted Waters

Type of Impact	River Miles	Lake Acres	Estuary Square Miles
1. a) Severely Impaired Uses	30,000	880,000	800
b) Moderately Impaired Uses	8,700	3.5×10^6	1,600
2. a) Threatened Uses	9,000	88,000	2,500
b) Total Assessed	404,000	15.4×10^6	19,000

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1. Figures exclude state of Alaska. Total river miles 1.8 million river miles, 39.8 million lake acres, and 32,000 estuary square miles, (ASIWPCA, 1986).
2. Contamination source -- point, nonpoint or mixed.

2.2 The Erosion/Sedimentation Process

Erosion is generally defined as the detachment and transport of soil by water, wind, ice or gravity (United States Department of Agriculture, Soil Conservation Society, 1980). The production of sediment is a process involving soil detachment, transport and deposition.

Erosion is a natural geological process that can be accelerated by agricultural activities. Erosion occurs as water moves across the surface of the soil. However, not all sediment eroded from the earth's surface enters streams or lakes. Generally, the larger and heavier sediment particles are deposited on the gentler slopes during transport, leaving the finer particles in suspension. Finer particles (such as clays) have higher chemical absorbing capacities than the coarse particles. The nutrient-rich organic matter is relatively light and is also associated with fine particles. Thus, sediment that reaches water bodies contains greater concentrations of clays, organic matter, nutrients, and pesticides than the original soil matrix.

Plants and plant residues usually provide adequate moisture and protective cover to soils. If moisture is too low or the protective cover is removed, the land may become vulnerable to periodic erosion. Certain tillage practices remove or bury the protective cover and exacerbate erosion.

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Erosion is further stimulated by rainfall and other run-off producing hydrologic events. BMP`s, if employed properly, can keep soil in place and prevent loss of sediment through runoff. Research has shown that the largest share of nutrients in cropland runoff is associated with sediment (Omernik et al. 1981).

Researchers have observed a striking relationship between rainfall runoff and total pollution contribution. One study determined that although rainfall runoff accounted for only 32.3 percent of the total runoff (the remaining 67.7 was caused by snowmelt), it was responsible for 93.7 percent of the suspended matter and 61.8 percent of the total organics lost in the runoff. Almost all of the soil loss was attributed to one-third of the runoff caused by rainfall (Harms et al. 1974).

2.2.1 Estimation of Sediment Loads

The potential for sediment delivery (from a farm field to the receiving water) depends on a variety of site characteristics including slope, climate, and proximity to surface waters. In addition, crop type, tillage practice, and other crop management considerations, account for the fact that all croplands do not contribute equal amounts of sediment to surface waters.

Interest in the development of techniques for

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estimating soil losses from agricultural activities began in the early 1940's when equations based on length and percentage of slope were developed to account for crop and soil conservation factors.

In the late 1950's, Wischmeir and others restructured and improved earlier equations and developed a relationship called the Universal Soil Loss Equation (USLE). This equation can be used in evaluating the effects of various management techniques on soil loss from agricultural lands (Table 1, Appendix B).

The Universal Soil Loss Equation can predict the amount of soil lost or eroded from its original position and moved to the bottom of the slope (i.e., where the ground becomes flat); however, the equation does not account for any changes in the sediment load that may occur during movement toward the water body. These changes are usually in the form of deposition between the bottom of the slope and the receiving stream and can be related to many factors, including distance between the farm site and the receptor stream and the character of the intervening terrain--its roughness, cover, slope, and shape. Sediment yield (or load) is usually significantly less than gross erosion, often constituting only 5 to 10 percent.

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2.2.2 Factors effecting delivery of sediments to receiving water

Several investigators have undertaken to develop "delivery ratios" to link sediment load with potential gross erosion. (Roehl, 1962; Piest & Miller, 1970; William and Berndt, 1972). Delivery ratio is defined as the ratio of sediment yield to gross erosion. Unfortunately, there is no established mechanism for estimating sediment delivery ratios. Stewart et al. (1975) indicated that the delivery ratio has been observed to be roughly inversely proportional to the 0.2 power of the drainage area (in acres). Because of its exponential nature, such a relationship makes little distinction in the delivery ratio for basins over 40 to 50 acres in size. Other factors such as density of soil and slope may have more significant effect on the delivery ratio than the area drained.

Surface soil texture may be particularly important to sediment delivery. In the Great Lakes basin, it has been found that areas with predominantly clay surface soils often have relatively low potential gross erosion rates but high yields of sediments and associated pollutants (PLUARG, 1978). Although a few researchers, including McElroy et al. 1976, have attempted to relate soil texture to delivery ratio, the relationship is not readily usable. Thus, a widely applicable equation for pollutant delivery ratio, that would allow direct calculations of potential gross

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erosion, remains a major research need (Roehl, 1962; Piest and Miller, 1970; Williams and Berndts 1972).

In addition, the effects of seasons and local climatic conditions represent possible weaknesses when the Universal Soil Loss Equation is applied to short-duration losses. During winter erosion can occur by frost movement and snow melting. Most precipitation in northern areas occurs as snow. Snowfall lacks the energy of rain and causes an insignificant amount of erosion. During the spring, however, runoff caused by snowmelt often acts as a scouring agent and can remove large quantities of soil. Such processes can cause large errors in the soil loss predictions, especially in short-term projects involving winter or spring months.

2.2.3 Available Data

A review of the literature reveals that considerable data are available on sediment losses associated with various BMP's. However, most of the results are derived from simulation models rather than from actual field studies. Field studies, on the other hand, have great variations in their parameters, since they have been conducted under specific (local) conditions including major storm events that occur only once or twice over a long period of time. Thus, field monitoring requires a very long period for generating useful results, and is expensive. A period of 10 to 20 years is very common for conducting field studies, whereas simulation models can be developed more rapidly. However, simulation studies lack the reliability of field studies.

It must be recognized that most studies reviewed during the course of this project are difficult to compare because of their differing approaches and objectives. Few of the studies reviewed had the objective of developing information pertaining to effectiveness of soil conservation practices in terms of cost per pound of pollutant removed. These studies are primarily concerned with determining the cost of implementing a specific BMP for specific farmland.

Presently, a number of Rural Clean Water Projects (RCWP's), Model Implementation Program (MIP) projects, Agriculture Conservation Program (ACP) Special Water Quality Projects, and the Integrated Federal Water Quality Management (IFWQM), are designed to demonstrate the effectiveness of various control measures.

IFWQM projects, funded by EPA, are an integral part of EPA's water quality management efforts to control pollutants from agricultural and silvicultural activities. They are aimed at accelerating the implementation of nonpoint source control programs, and the application of BMP's in the areas and sources of pollutants that contribute to a region's water quality problems. Under actual field conditions, various projects will evaluate the effectiveness of the soil conservation practices recommended by EPA as a tool for curtailing pollution loadings from croplands to surface waters. A list of RCWP's is contained in Table 3. Telephone contacts with the project officers revealed that these projects are still in their early stages and to date their results have not been compiled in any useful format. Data extracted from various studies reviewed are listed in Tables A-1 to A-3 (Appendix A).

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Table 3 Rural Clean Water Projects*

Project Name/Code	Project location/State
Lake Tholoeco/8801	Alabama
Appoquinimink/8802	Delaware
Rock Creek/8803	Idaho
Highland Silver Lake/8804	Illinois
Prairie Rose Lake/8805	Iowa
Bonne Idee/8807, and	
Double Pipe Creek/8808	Maryland
Saline Valley/8809	Michigan
Reel Foot Lake/8810, and	
Snake Creek/8811	Utah
St. Albans Bay/8812	Vermont
Lower Manitowoc Taylor Creek-	
Nubbin/8813, and	
Slough/8814	Florida
Westport River/8815	Massachusetts
Garvin Brook/8816	Minnesota
Long Pine Creek/8817	Nebraska
Tillamook Bay/8818	Oregon
Conestoga Headwaters/8819	Pennsylvania
Oakwood-Lake Poinsett/8820	South Dakota
Nansemond-Chuckatuk/8821	Virginia

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*Source Personal communication with James Krider, October 1985 National Environmental Engineer, U.S. Department of Agriculture, Washington D.C.

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2.3 GENERAL NATURE OF NUTRIENT TRANSFORMATION

During a storm event and/or snowmelt, runoff from the land surface carries materials, sediments, nutrients, and pathogens into waterways. Movement of water in the soil profile, whether downward and through a water table, or upward in response to surface evaporation, carries soluble materials. Water that does not infiltrate but flows over the surface carries sediments, chemicals, bacteria and other materials to water bodies. Depending on flow conditions these pollutants can be deposited and re-entrained. Both chemical interaction and transformation affects pollutant concentration in transport. Chemical interactions determine the concentrations of pollutants in sediment and runoff water. Some chemicals are soluble in water and move in solution. Other chemicals adsorb (attach) readily to soil particles.

Most chemicals demonstrate a balance between the amount in solution and the amount adsorbed. However, the balance point is dynamic and changes with flow conditions. It also takes a finite period of time to reach equilibrium. The amount transported depends upon the amount in solution and the amount adsorbed. Soluble pollutants move with the water either through the soil to the ground water or over the surface through the stream systems. Adsorbed materials move only when the soil particles move.

Pollutant transformations determine the form or composition of a pollutant. Many biological processes and chemical reactions influence transformation processes. For example, nutrients undergo many transformations that determine their pollution potential and transportability. Some forms are highly soluble. Others are readily adsorbed to soil particles. Some forms of degraded pesticides are more toxic than others.

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2.4 PHOSPHORUS--ITS ROLE, MOVEMENT, AND TRANSFORMATION

Increasing evidence has implicated phosphorus as a major factor accelerating eutrophication in lakes and other water bodies (Stewart and Rohlich, 1967; Lee 1970). Although discharges of municipal and industrial effluents are major contributors of phosphorus to surface waters in the United States, runoff from agricultural and urban areas can transport large amounts of phosphorus (P) into streams and lakes. The National Eutrophication Survey (1975), concluded that streams draining agricultural watersheds, had mean concentrations of total N nearly nine times those from forested watersheds (Humenik et al. 1982). Data indicates that cropland runoff accounts for 20 percent of P loadings and 25 percent of the N. Animal wastes contributes 12 percent of the P and 23 percent of the N (Humenik et al. 1982). The nonpoint sources of P will assume even more importance in the future as loadings from point sources are reduced by advanced wastewater treatment.

Phosphorus in runoff consists of dissolved forms of P, organic and inorganic compounds and organic and inorganic P associated with suspended sediment that is detached from the soil mass and transported by flowing water. Similarly, the drainage water and subsurface water discharging into streams and lakes may transport significant amounts of dissolved P. There is also a small amount of dissolved P in precipitation falling directly on lakes and streams.

Nonpoint sources (NPS) of P are difficult to identify and control because of their diffuse nature. Most attempts at control of NPS of P pollution involve the adoption of a prescribed practices in the use and management of land, to minimize P discharges in drainage water and surface runoff.

A large body of knowledge has been developed concerning the chemistry of P in soils. However, much of this work has centered on processes relating to the availability of P in soils to agricultural crops. Relatively little research has been done on the algal availability of P associated with soil derived materials present in aquatic systems. In addition, processes responsible for transport of P in lakes and streams have been inadequately investigated (Logan, 1986).

2.4.1 Forms of Phosphorus

Phosphorus exists in many forms and there is much confusion among scientists as to the proper use of the terms describing these forms. Much of the confusion results from the methods used to measure P forms and the interpretation made about P analyzed by different procedures.

Phosphorus can be classified by physical state (e.g., dissolved, particulate) and chemical type (e.g., H_2PO_4, Apatite). Although P can exist in gaseous form, this is not a common occurrence in nature.

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Phosphorus associated with solids has been referred to as particulate P, sediment P and sediment-bound P, especially in relation to fluvial systems, (i.e., anything pertaining to or produced by the action of a stream or river). Sediment-bound phosphates include organic and inorganic forms, but the inorganic fraction contains most of the P that can be released into water. Various forms of particulate and dissolved phosphates are shown in Fig. 1.

Though particulate P can be of many forms, the following list includes those most likely to be environmentally significant (Logan 1981):

1.	Adsorbed:	labile P; exchangable P
2.	Organic:	various forms including phytins (inositols) and phospholipids
3.	Precipitate:	primarily in soil; fertilizer reaction products with Ca, Fe, Al and other cations; varying with water solubility.
4.	Minerals:	amorphous, short range order and crystalline minerals with Ca, Fe, Al and other cations.

Phosphorus in solution is normally considered to be orthophosphate, inorganic phosphates, and organic P compounds dissolved in the water phase. However, the separation of particulate and liquid phases of water samples is somewhat arbitrary and rarely complete. The standard separation procedure involves filtration through 0.45um pore diameter membrane filters (American Public Health

VIKING

Association, 1975). The P in the liquid phase (filtrate) is operationally defined as "dissolved P", "soluble P", "filtered reactive P" (instead of dissolved), and "ortho P" (which could include some particulate P). Among these, the most widely used definitions are "dissolved P" and "soluble P" (Logan, 1986).

Total P commonly refers to all forms of P runoff or stream sample (dissolved and particulates in suspension) as measured by a chemical procedure involving rigorous digestion with strong acids such as perchloric, and nitric-perchloric. Much water quality monitoring involves determination of total P by digestion of an unfiltered sample. Total P levels in sediments are determined by the levels of inorganic and organic P, which are probably largely controlled by independent factors such as the soil texture, amount of organic matter and amounts of Fe and Al (Williams et al. 1971). Thus, due to several factors influencing the accumulation of P in sediments, considerable variation is reported in the literature in total P values. For example, Williams et al. 1971 reported values ranging from 580 to 7,000 ug/g. for calcareous and noncalcareous sediments from Wisconsin Lakes, the noncalcareous sediment usually containing larger amounts of total P.

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P Fraction		Chemical Characteristics	Percent Bioavailability
Total P	Total Dissolved P	Dissolved Inorganic P e.g., orthophosphate ($H_2PO_4^-$)	>90
		Dissolved Organic P a) Nucleic acids b) Inositol c) Others	<50
	Total Particulate P	**LABILE P** Includes adsorbed, exchangeable, easily dissolved, easily hydrolozed.	Potentially - 100 percent Immediately - unknown
		Inorganic P Relatively stable, primary and secondary minerals Fe, Al, Ca.	Potentially - unknown Immediately - unknown
		Organic P Relatively stable humus compounds such as inositols.	Potentially - ? (50) Immediately - 0

FIG:1 Different Forms Of Phosphorus And Their Availability

2.4.1.1 Bioavailable P

Bio-available P is measured by a bioassay technique which quantitatively determines the concentration of a substance by its effect on the growth of a suitable animal, plant or microorganism under controlled conditions. Although the terms "dissolved inorganic P" and "bioavailable P" are interchangeably used, most researchers agree that only 75 percent of "dissolved inorganic P" is bioavailable (Williams et al. 1971, Logan 1986). Of total particulate P (TPP), only 20 - 30 percent is bio-available (Logan, 1986). Because of the potential impact of phosphorus on aquatic systems, interest usually focuses on the algae-available phosphorus fraction. This fraction can be as small as the labile P fraction which it contains, or include nearly the total P fraction. Labile P is the most plant- and algae-available phosphorus fraction and is partitioned between the water and sediment phase. Labile P can be transferred completely from the sediment phase to the water phase of runoff with leaching by water low in phosphorus, and usually ranges from 10 to 40 percent of the total P fraction (Harms, 1975).

2.4.2 Phosphorus and Sediment Interaction

Sediment is both a source and sink for P. P is strongly adsorbed by soil or sediment and rapidly (in less than 24 hours) equilibrates with it. The majority of P in agricultural runoff is attached to the sediment. The dissolved P concentration in runoff, is determined by the sediment load and the buffer capacity of the sediment. Soils with large inputs of fertilizer or manure P, usually maintain higher dissolved concentrations of P than soils with little or no P input. For example, subsurface soil eroded by streambank scour, will maintain much lower dissolved concentrations of P than surface soil. Because of the strong affinity of sediment for P, concentrations of point source P, discharged into streams carrying a sediment load, will be reduced as the sediment adsorbs the "point" source P. The ratio of dissolved to sediment-bound P monitored in a stream, is determined by the sediment concentration and the capacity of the sediment to absorb the P. This can be estimated from an adsorption/desorption isotherm partition coefficient.

Sediments can get enriched in P by the following ways:

(1) Adsorption of P on clays.

(2) Chemical precipitation of iron, aluminium and/or calcium phosphate.

(3) Higher concentration of clays in sediment.

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Much of the sediment bound phosphorus is not bioavailable. Because of P enrichment of sediments, the erosion control practices show promise of reducing total P (TP) in runoff and, presumably, TP inputs to surface waters. Normally, however, not all of the TP in runoff is equally available to aquatic plants. Soluble inorganic P is considered to be most readily available P. A portion of the sediment bound P may also become available by desorbing from sediment as soluble levels are depleted. In a water body where algal growth is blooming, P levels may be reduced to such an extent that P from the sediment may come into solution.

In many soils, most sediment phosphate is combined with ferric ions. Under anaerobic (reducing) conditions in muds or stream sediments, ferrous phosphate is formed which is more soluble than ferric phosphates. Topsoil washed into streams and lakes, contains much P that is potentially useful to aquatic life. In water, the solubility of soil phosphate may be increased so that it becomes a good source of P for aquatic plants in shallow water bodies. The dynamics of availability of sediment phosphorus to the overlying water depends on P concentration of sediment porewater which in turn depends upon the affinity of solid sediment phase for P. In lakes and coastal waters, a substantial fraction of P becomes irretrievably deposited into the sediments; and with increasing depth of the lake, net removal of P from the water by sediments becomes preponderant and the quantity of P reduced by sediment becomes small.

2.4.3 Runoff Losses of Phosphorus

As rainwater falls on the soil, some particles are detached from the soil mass and transported in the water running off the area. A portion of the detached particles settles in various locations. Other particles (usually with small particle size and/or low density) are discharged into small streams and subsequently transported into larger streams and lakes. The erosion process is selective for finer particles; that is, a greater proportion of the eroded sediment is made up of smaller size particles as compared to the proportion in the soil. Smaller size particles normally contain higher concentrations of organic C, N, and P than coarser particles, because most of the organic matter, iron and aluminum hydrous oxides are present in the clay fractions of soil. Thus, the eroded sediment has a higher P concentration than the soil from which it was derived and is said to be enriched with P.

The term "enrichment ratio" has been used to describe the ratio of the P concentration in the eroded sediment to that in the soil. Enrichment ratios for particulate P can vary from 1 to 10 depending on the size of the watershed, erodibility of soil, and rainfall intensity. For relatively

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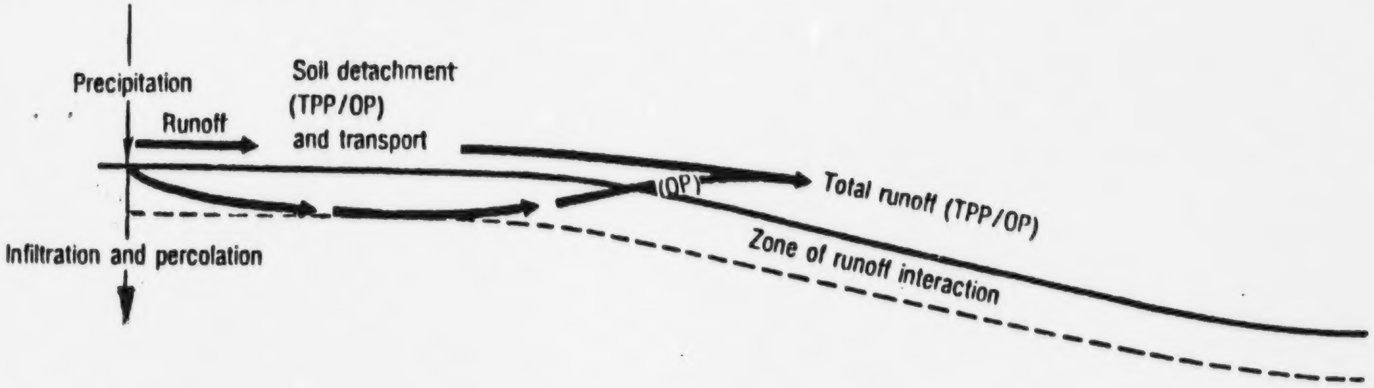
large watersheds (approximately 5000 ha.) enrichment ratios of 2 to 6 are common (Nelson et al. 1980).

However, when soil erosion is controlled, is naturally low, or is very localized within a watershed, nonerosional factors may become important contributors of P in a watershed. These factors include the P fertility level in soil, placement of fertilizer P, and P leached from plant tissue and residue. Under these circumstances, nonerosional sources of P can be major and largely soluble, and the conventional wisdom that P loss is a function of soil loss may not apply.

2.4.3.1 Point/Nonpoint Source Interactions

The phosphorus runoff leaving the field undergoes significant change during its transport through the stream system to the lake (Fig. 2). During transport, suspended sediments from upland sources may interact with concentrated, dissolved, phosphate "point" discharges. Taylor and Kunishi (1971), reported a rapid adsorption by upstream suspended sediments of a concentrated P discharge, from a swine feedlot in rural Pennsylvania. Verhoff (1982) reported higher P adsorption from sewage, during storm events when the stream had a higher concentration of sediments. Other researchers (McCallister and Logan, 1978; Green et al. 1978), studied the phosphate characteristics of agricultural soils and suspended stream bottom sediments, in

Fig. 2 **PHOSPHORUS TRANSPORT IN RUNOFF**


Precipitation
Runoff
Soil detachment
(TPP/OP)
and transport
(OP)
Total runoff (TPP/OP)
Zone of runoff interaction
Infiltration and percolation

TOTAL PARTICULATE PHOSPHATE (TPP) TRANSPORT

Selective transport of clay and organic matter in runoff gives sediment that is enriched in phosphate; proportion of clay in sediment increases as soil loss decreases, which increases P enrichment (Fig. a).

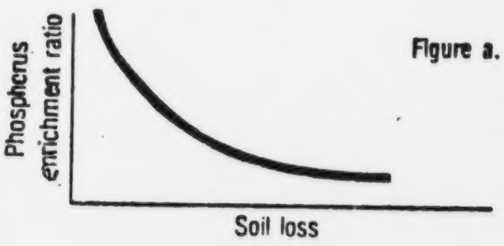


Figure a.

SOLUBLE PHOSPHATE (ORTHOPHOSPHATE OP) TRANSPORT

Soluble P in runoff includes P held in soil pores in the zone of runoff interaction, dissolution of soluble P compounds in the soil, P leached from decomposing surface plant residues and desorption of P adsorbed on soil particles. Soluble P equilibrates with sediment in runoff by adsorption/desorption. (Fig. b)

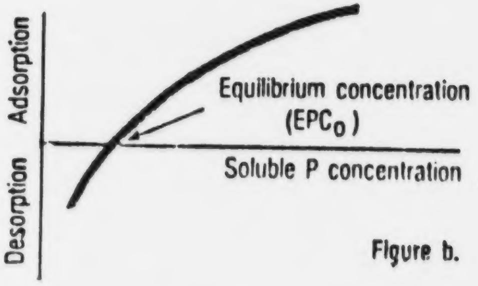


Figure b.

the Maumee River Basin of Ohio. Their findings indicated that the clay fractions of the surface horizons of agricultural soils were enriched in total P; and that the stream bottom sediments also showed a similar enrichment. However, the suspended sediments had much higher enrichment than would be predicted from the clay fraction enrichment. It was assumed that due to strong affinity of P for sediments, the suspended sediments have adsorbed additional dissolved P from `point' sources in their passage through the stream system.

2.4.3.2 Effects Of Agricultural Land Management on the Transport of Particulate and Dissolved Phosphate in Runoff.

Since the particulate, or sediment-bound phosphate constitutes a large percentage of the total phosphate load from cultivated agricultural land (with particulate P more than 75% of total P), erosion control remains the most effective method for reducing the total phosphorus load from this source. BMP's such as conservation tillage, especially no-till, can achieve significant erosion control (in many cases more than 90%) by protecting the soil surface. In Logan's review (1981), of the effects of conservation tillage on phosphate losses from agricultural land, he found that no-till, while quite efficient in reducing the total particulate phosphate load, increased, or had no effect on the dissolved P load. There are several reasons for this. In a nonequilibrium soil (such as one fertilized or limed,

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where the phosphate added has not reacted completely with the soil minerals), there are significant amounts of P held in soil pores, precipitated as soluble compounds, and adsorbed on soil surfaces. During runoff, some of this P is removed and comes to equilibrium (or near equilibrium) with the sediment in the runoff. When no-till is used, the amount of sediment in the runoff decreases dramatically since the presence of crop residues decreases detachment of soil particles. The runoff volume, however, is changed to a lesser extent. Therefore, the amount of dissolved P initially removed during runoff is similar to that from conventional tillage, but there is less sediment in the no-till runoff to adsorb the dissolved P load. The amount of dissolved P under no-till is greater as compared to conventional tillage. Other reasons for higher dissolved P levels with no-till are the build-up of fertilizer P on the surface of no-till soils and the leaching of dissolved P from decaying plant residues. McDowell et al. (1980) have reported similar results.

This research indicates that, while "no-till" can be expected to greatly decrease soil losses on land previously under conventional tillage, the main effect on phosphorus loads will be to significantly decrease the particulate P. However, there will be no change, or even an increase, in dissolved P. Under such conditions, it would be wise to consider other management practices, particularly proper

VIKING

fertilizer use for controlling dissolved P.

2.4.4 Best Management Practices for Phosphorus Fertilizer Use and Application/Implications for P in Runoff

When fertilizer P is applied to the soil, it is generally 100 percent orthophosphate, i.e., it is potentially all crop available. However, it reacts immediately on application with the surface soil (0-20 mm) with which it is in contact, and much of it is rendered insoluble and unavailable to plants. Long-term soil fertility research has shown that after field application, only about 10 to 20 percent of the fertilizer P remains available to plants (Logan, 1981). The resulting unavailabe forms, include highly insoluble precipitates of P with soil-containing cations such as Fe, Al, Mg, Ca, and others; and P that has been adsorbed and diffused into small mineral surfaces. The available forms, include dissolved P in soil pores and labile; and adsorbed and diffused P on soil mineral surfaces. The chemistry and mineralogy of a particular soil will determine the extent to which fertilizer P is converted to available and unavailable forms. The balance of P between these forms will affect the amounts of particulate and dissolved P in the runoff. The term "available P" means available to crops and is determined by standard chemical extraction techniques, developed by (Bray and Kurtz, 1945), and called Bray's P1. Other authors, including Smith et al. (1979) have shown that

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where P was applied in excess of crop needs Bray's P1 sediment P losses increased. A significant finding was that the greatest increases were with no-till practices. Fertilizer P increases the available P level in soil and dissolved P in soil pores. Also, at higher available P levels, the equilibrium between adsorbed P and P in solution is shifted toward higher dissolved P concentrations. If runoff volumes and soil losses remain the same, P fertilization in excess of crop needs should increase dissolved P losses in runoff. Several researchers using different approaches have clearly demonstrated this relationship. For example, Romkens and Nelson (1974) found a highly significant positive relationship between dissolved P concentrations in runoff and Bray's P1, extractable P in the sediment. In another study, placement of fertilizer P on the soil surface, either above or below the crop residue, gave much higher soluble P losses than non fertilized plots, or plots where the fertilizer was injected below the soil surface (Baker, 1980). This is because surface-applied fertilizer P builds up very high levels of available P at the soil surface and part of this is desorbed during runoff to become dissolved P (Oloya and Logan, 1980).

2.4.5 Point Versus Nonpoint Phosphorus Control

Water quality managers and planners are faced with difficult decisions on how to best reduce point and nonpoint pollutant input to water bodies. Given the economic

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realities of today, these decisions must be cost-effective. Decision-makers must, therefore, be careful to select the combination of point and nonpoint water quality control measures which will most efficiently solve their pollution problems.

In developing a strategy to compare point versus nonpoint P controls in a watershed, the following information is required:

(a) the distribution of all P sources in the watershed by type (point versus nonpoint), magnitude, and location;

(b) a list of BMPs for control of each P source, effectiveness of each BMP for control of particulate and dissolved P, and cost of each practice; and

(c) partitioning of each P source into particulate and dissolved loads. Also needed is long-term record of particulate and dissolved P loads at the point of entry of flow into the impacted water body (e.g., lake or estuary).

With this information and some type of sediment and water routing model such as CREAMS or HSPF, one can calculate the effect of each BMP on reduction of P delivered to the point of discharge, as well as cost-effectiveness ($/kg) of P reduction. By partitioning the load into particulate and dissolved P, one can also determine the reduction in bioavailable P by assuming that 90-100 percent of the dissolved P is bioavailable, and that 20-30 percent of the particulate P is available. These assumptions are based on work done in the Great Lakes Basin by the Army

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Corps of Engineers Wastewater Management Study and others, (Logan, 1986). In situations where there is mixing of point and nonpoint discharges (as in a stream), a reasonable assumption is that the point source load, which is primarily dissolved, will partition into the sediment load in the same ratio as measured at the watershed mouth. In looking at the relative cost-effectiveness of point and nonpoint BMPs, this can be done in a step-wise manner in which the most cost-effective practice is assumed, the load reduction is calculated and applied to some target load reduction; the second most cost-effective practice is assumed and the load reduction calculated, and so on until the target load is achieved. Alternatively, one may wish to choose one practice as the primary practice and then screen other practices as candidates to meet the required load reduction.

A methodology referred to as "watershed" (Sonzogni et al. 1980) for evaluating alternative point and nonpoint source control within a drainage area has been developed by U.S. EPA. "Watershed" allows the user(s) to estimate loadings from each major pollutant source and to examine load reductions and costs associated with control options. Point and nonpoint source control strategies can then be ranked on the basis of cost per unit reduction in pollutant loadings to the receiving water. From this ranking, an optimum mix of programs can be identified, which will achieve a required load reduction at the least cost. As

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indicated earlier, strategies can be staged, that is, they may consist of several levels of control.

2.4.6 Controls for Phosphorus Loss/Role of BMP's

A review of the literature regarding P control mechanisms has shown that strong conclusions are based on scanty and incomplete data (Humenik et al. 1982). Except for the Corn Belt where more data is available, the assumption has been that erosion control practices limit P losses because most P is associated with sediment carried in surface runoff. Very few studies have addressed P leaching into groundwater and subsurface flow as related to surface runoff controls. Because the literature regarding P control mechanisms, is limited, only a few conclusions can be drawn about their effectiveness:

- contour farming can reduce total P losses by limiting sediment and water runoff. Reductions in total P loss generally range from 35065 percent (Bos, 1983; International Joint Commission, 1983); however, the reduction in soluble P is usually in the range of 20-25 percent (Logan and Forster, 1982).
- soil conservation practices such as residue management, sod-based rotations, and rotation grazing can decrease total and soluble P losses in surface runoff (Logan, 1986; Burwell et al. 1977).
- conservation tillage practices generally reduce total P discharge, as compared to conventional tillage. However, conservation tillage practices can increase soluble P losses as compared with conventional tillage.

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For field crops in the eastern half of the United States, the following conclusions can be drawn regarding the effectiveness of various BMP's for P pollution control (Haith et al. 1979).

- contouring, sod-based rotations, and conservation tillage (including no-till) significantly reduce edge-of-field losses of particulate P by reducing erosion.
- sod-based rotations significantly reduce losses of soluble P in surface runoff.
- conservation tillage practices that involve residue management, due to nature of residues, types of crops grown etc., have uncertain effects on losses of soluble P in surface runoff. Since many of the conservation tillage practices reduce erosion, they also reduce total P. Reductions in total P of 89 percent of reduction in soil loss have been reported (Logan, 1986).
- contouring that also uses residue management moderately decreases losses of soluble P in surface runoff.

When developing a P management strategy for a water body such as a whole lake or a portion of a lake, positional constraints as well as the potential bioavailability of the total P sources should be considered. For example, in deep lakes with little re-entrainment of sediment particulate material back into photic zone, the opportunity for algae to utilize potentially bio-available particulate P will be minimized. For such lakes, a nonpoint management strategy that is limited to controlling sources high in soluble P may be particularly cost-effective. Such practices include control of excessive fertilizer application (Oloya and

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Logan, 1980), and some forms of livestock waste management (Porter, 1975). On the other hand, in shallow waters or flowing streams where sediment material is frequently resuspended, particulate P sources, even though partially bioavailable, may be relatively important, especially if the particulate load is high. Here a management strategy may need to consider reducing inputs of particulate, as well as soluble P. For instance, in the shallow western basin of Lake Erie, the large particulate P load may play a significant role in lake productivity, since particulate material delivered to the lake tends to be repeatedly resuspended and bio-available to algae in the photic zone (Logan, 1982). Further, since many particulates that enter the western basin are eventually deposited in the central basin (Herdendorf and Zapotosky, 1977), there is the possibility of additional release of P (especially Fe-P) when the central basin becomes anoxic in the late summer.

VIKING

2.5 TRANSPORT AND FATE OF NITROGEN

Like phosphorus, nitrogen plays a major role in the eutrophication of water bodies. When other factors are under control, total nitrogen (N) concentrations as low as 1 to 2 mg/l can support algal blooms (Humenik et al. 1982). However, for most of the aquatic biota, phosphorus is more limiting than N. While phosphate concentration as low as 10 to 20 mg/l can support algal growth, N requirements may be hundred times as high (Humenkin et al. 1982, Sharpley, 1985). Nitrogen is also not essential for the growth of some forms of algae such as blue green algae, which can meet their N requirements by fixing atmospheric N.

Nitrogen occurs in various forms in soils, such as in association with the clay fraction, fixed on the surfaces of the clay particles, and as organic nitrogen (Fig.3). Concentrations of nitrogen in sediments are usually many times higher than concentrations of dissolved nitrogen in runoff. The high concentration of nitrogen in sediment is related to the fact that ammonium ions being positively charged have a high affinity for negatively charged clay particles. In certain expanding type clay minerals such as vermiculite, montmorillorite and illite, NH_4 may be fixed between the two layers of these minerals. In addition to the association of NH_4^+ with clay particles, sediments may also have nitrogen in the organic fraction. This organic nitrogen may be part of the microbes sticking to the sediments or may be part of

Nitrogen Fraction.		Chemical Form.	Percent Bioavailability.
Total N	Total Dissolved Nitrogen	Dissolved Inorganic Nitrogen. e.g., NO_3, NH_4	100 Percent
		Dissolved Organic e.g., Some Amino Acids	100 Percent
	Total Particulate N.	Labile - N (NH_4^+) adsorbed on clay	Potentially 100% Immediately - Unknown
		Organic - N part of humus	Potentially - Unknown Immediately - 0

Fig:3 Particulate and Dissolved Nitrogen In Soils and Sediments (Logan, 1986) the resistant organic matter such as humus. The nitrogen in dissolved form is mainly present as nitrate. The nitrate ions being negatively charged are not retained by the clay surfaces. Nitrate concentration relative to ammonium forms in surface runoff is normally high. Nitrates are the preferred source of N for the majority of plant and microbial communities. Nitrates in agricultural runoff can come from fertilizers, manures or decaying organic matter. In addition, the form of N applied to the soil greatly affects the nitrate concentration in surface runoff. In a sandy soil, almost all of nitrogen applied as nitrate can be leached out of the soil profile. Nitrates may also be contributed to the surface waters via the nitrification whereby ammonical nitrogen is oxidized to nitrate nitrogen.

Nitrification is catalyzed by two groups of bacteria namely nitrosomonas and nitrobacter. Nitrosomonas converts ammonical nitrogen to nitrites and nitrobacter group further oxidizing nitrites to nitrates. The conversion rates from nitrites to nitrates are higher than the conversion rates of ammonical to nitrite. Nitrites, therefore, rarely accumulate in surface runoff and concentrations of nitrates in runoff relative to ammonium are normally higher, while the reverse generally occurs in sediments. All forms of nitrogen are in dynamic equilibrium with each other. Transformations are biologically mediated and depend upon the biochemical and chemical environment of the sediment.

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In aquatic systems, the biochemical processes responsible for N-transformations are primarily immobilization and mineralization. Immobilization incorporates inorganic nitrogen in a living biomass, thereby removing available N from the water column. In most aquatic and terrestrial systems, mineralization, the process of conversion of organic nitrogen to inorganic nitrogen, occurs simultaneously and the net change in nitrogen status at any given time is reflected in the biomass level. The relative roles of various biological entities (bacteria, fauna, and flora), responsible for N assimilation and release vary with the chemical environment of the sediment. For example, in acidic soils, fungi as compared to bacteria will be more active in the nitrogen transformation. On the other hand, in sediments with easily decomposable organic carbon, immobilization will be dominant over mineralization. However, once the organic carbon is consumed, the biomass will start decaying and N by the process of mineralization will be released from their body tissues.

In agricultural watersheds, N is transported in both sediment and solution phases in the forms of nitrate, ammonium, and organic nitrogen. In surface runoff, concentrations of nitrates relative to ammonium are normally higher; the reverse generally occurs in sediments. The solution phase is the primary mechanism for easily available inorganic forms of nitrogen. Moreover, the form of nitrogen

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applied to the soil greatly affects its leachability. In a sandy soil, almost all of the inorganic nitrogen applied as nitrate can be leached out of the soil profile. Nitrite levels in soils are usually low due to their rapid conversion to nitrates. In case of soluble organic nitrogen, movement or leachability depends primarily on two factors, ease of adsorption/resistance to desorption and water solubility. Both these factors are in turn dependent on soil characteristics, primarily soil moisture and temperature.

The source of ammonium ions in sediment and runoff is the fertilizer additions and mineralization of organic nitrogen. The ammonium nitrogen in sediments is normally assumed to be converted organic nitrogen. The conversion occurs from degradation during the process of ammonification. In one study, 52 percent of nitrate in organically rich sediments was converted to ammonia. In contrast, in organically poor sediments only 7 percent of nitrate was converted to ammonium nitrogen (Schwab et al. 1973).

In aquatic ecosystems, fungi and particularly bacteria have traditionally been assumed to be major decomposers, releasing mineral nutrients including nitrogen from organic matter. However, in many situations aquatic animals may dominate in the aquatic nutrient regeneration process. This statement is supported by the fact that herbivorus zooplankton, due to their rapid food consumption, release back into the water an amount of nutrients many times greater than their body concentrations. Nitrogen is excreted as ammonium, free amino acids and other organic compounds of nitrogen, that are then available for utilization by phytoplankton.

The relative proportions of the easily available and dominant inorganic nitrogen forms -- nitrate and ammonium in runoff from a watershed -- is influenced by the soil organic and inorganic exchange complex, leaching from soil or absorption by vegetation, precipitation, horizontal and downward movement of soil water, and an array of biological reactions.

N sediment water interactions, N cycling, and N availability are parts of a complex system and microbial reactions play an important role in sediment-water interchange of nitrogen. Although nature precludes eliminating all losses of applied nitrogen from soils to the environment, an understanding of individual components of this system is essential for the development of a N-management strategy for a waterbody or watersheds. For example, in deep temperate lakes, nitrate and nitrite levels are at a maximum in the spring due to biological utilization and/or denitrification, and minimal during late summer. In case of organic N levels, Domogalla et al. (1962), found that the concentration generally peaks during spring and early summer, though due to lake location and other factors,

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maximum organic N levels in surface waters can be found at any time during the year.

2.5.1 Nitrogen and Sediment Interaction

In runoff from an agricultural field, sediment N often consitutes a majority of the total N load. The sediment N is primarily organic N which is only mineralized at a rate of 2-3 percent a year. Most of the bioavailable N is in the dissolved fraction and 90 percent of that is nitrate nitrogen. Therefore, although sediment N is often an important component of the total load, it is not as important as the nitrate load. Nitrogen is a pollutant only because of its potential to contaminate drinking water as nitrate nitrogen when concentrations exceed 10 mg/l, and when dissolved ammonium concentrations are high enough to kill fish. The latter are associated with local discharges of high concentrations of ammonium nitrogen from manure or ammonium fertilizer only.

2.5.2 Role of BMP's in Controlling Nitrogen Losses

The literature establishes that a primary nitrogen control measure to reduce N in surface runoff, is to prevent excessive nitrogen applications. In addition, various components of nitrogen cycle can also be manipulated, including the use of slow release fertilizers or nitrification inhibitors, to decrease the rate of conversion of relatively immobile ammonium to highly mobile nitrate

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nitrogen.

Manipulating the nitrogen cycle can also be used for matching the conversion of native or applied nitrogen to plant-available forms. An effective N management strategy would also include information about N transformations in soil, sediments, and water. In receiving waters, nitrogen levels can be reduced if the N cycle in conveying streams is manipulated so as to increase denitrification. This can be achieved by providing denitrifying bacteria a food source, such as streamside vegetation rich in biodecomposable organic carbons. Robinson et al. (1982) has shown that maintaining streamside vegetation results in carbonaceous-rich materials from vegetation falling into streams. The metabolizable carbon from these sources acts as food for the denitrifying bacteria, facilitating the removal of nitrates.

To control nitrogen in lakes, factors such as forms of nitrogen, N-concentrations within the lake water, and positional constraints should be considered. In deep lakes with little reentrainment of sediment particulates back into the photic zone, the opportunity for algae utilization of nitrogen is minimized. For such lakes, therefore, a management strategy that is limited to converting most of the nitrogen to organic forms and fertilizer management may be particularly effective.

In shallow waters where sediment material is frequently resuspended, sediment bound organic or ammonium forms may be

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important. Here a management strategy may need to consider reducing the sediment as well as sediment-bound nitrogen. For instance, in the shallow western basin of lake Erie, the large amounts of sediment-bound N may play an important role in lake productivity, since particulate material delivered to the lake may be repeatedly resuspended and positionally bioavailable to algae (Logan, 1981).

The depth of sediments actively involved in the exchange process have been considered to be between 5 to 20 centimeters (Alberts et al. 1978; Burwell et al. 1977). Sediments may be disturbed by benthic organisms, rough fish, bubbling of fermentation gases, wind, boats, and currents. Clays and other inorganic colloids readily adsorb organic nitrogenous compounds. Studies addressing surface runoff losses of N demonstrate conclusively that most of the total N lost in surface runoff is associated with sediments (Alberts et al. 1978, Burwell et al. 1977). Therefore, effective sediment control practices should reduce total N losses in surface runoff.

The obvious importance of sediments as a sink or source of N to waters, indicates that considerable effort must be put into quantifying N uptake and release from sediments. Various interacting processes, together with concise information on outside sources of N, must be used in realistic modeling efforts. A major pressing need is to develop reliable methods to determine the nutrient's availability in

VIKING

varying natural environments, as well as to develop estimates of the amount of N contributed to waters by algal and microbial fixation. Quantifications of the rates and magnitude of nitrification, ammonium exchange, N regeneration, denitrification, and immobilization in lake sediments in varying environmental conditions are also needed.

The literature indicates that methods of fertilizer application and appropriate agronomic practices can significantly reduce N losses from agricultural lands (White, and Plate 1979). In addition, the following conclusions can be established:

- crop rotation, no-till, and conservation tillage may reduces N losses in surface runoff (Burwell et al. 1975; Klausner et al. 1974; olness et al. 1975).
- contouring, conservation tillage and no-till may moderately reduce soluble N losses in surface runoff by reducing surface runoff. These practices may increase soluble N losses in subsurface drainage (Logan, 1986).
- sod-based rotations significantly reduce losses of soluble nitrogen in surface runoff (Olness et al. 1973).
- in general, contouring, terraces, sod-based rotations, conservation tillage, and no-till significantly reduce edge-of-the-field losses of particulate N because they reduce erosion. In addition, except for sod-based rotations, other practices reduce soluble nitrogen losses in surface runoff by reducing surface runoff. These practices may however increase soluble N losses in subsurface drainage.
- sediment control mechanisms, especially terraces, will greatly reduce total N loadings to surface waters (Burwell et al. 1977).

- cover crops can reduce nitrate leaching, increase soil organic matter, and reduce erosion from 40 to 95 percent. Legume cover corps provide available N for subsequent crops.
- management of nitrogen fertilizer applications and irrigation practices to meet crop needs can reduce soluble N losses in both runoff and percolation. Moreover, incorporation of slow release nitrogen fertilizer can be used effectively to reduce N losses to surface and ground waters (Gilliam et al. 1979; Dunigan et al. 1976).

VIKING

2.6 NUTRIENT LAG TIME

In devising policies for controlling pollutants in runoff from agricultural watersheds, both quantity and concentration of the pollutant must be considered. Quantity refers to the total amount of pollutant in the runoff and includes pollutants adsorbed on sediments. Concentration refers to the amount of pollutant in the solution phase. Concentration of nutrients in the receiving water is one issue of concern. The effectiveness of control actions and policies in effecting the desired changes in ambient nutrient concentrations may not be reflected in proportional water quality improvement, in the receiving water bodies. This is because some of the pollutant from the sediment phase will be released to the solution phase when conditions are appropriate. Thus, conservation or pollution abatement practices, should be aimed at lowering pollutant concentrations to below the level at which it has minimum environmental impact. The period of time between the reduction of input of the pollutant in question and perceptible water quality improvements is called "lag time".

The "lag time" describes the transport time from the land surface to the receiving water body, and the extent the pollutant is removed by the system before it can get into the water body. Lag time is also related to the ability of the soil/stream/lake system to buffer against change. Lag is a function of the size of a watershed or receiving water body and the amount of sediment in runoff and is the bottom of the receiving water. If a watershed is shallow and has large amounts of sediment, lag time is greater for pollutants that interact with other constituents of the stream and stream sediments. Phosphorus will have a longer lag time than nitrogen because nitrogen is easily lost as nitrate. Moreover, the surfaces of sediment particles have an affinity for phosphorus and no affinity for nitrate. This is because in the soil nitrogen occurs mainly as nitrate and ammonium; the nitrates being negatively charged, have no affinity for clay surfaces, which are also negatively charged. On the other hand, ammonium, being positively charged, is retained on the clay surface. Thus nitrates are not retained by clay while ammonium is bound by clay. In addition, some of the nitrogen may be reduced to ammonium by the process of nitrate dissimilation. Through this process, nitrogen at low oxygen concentrations is converted from nitrate to ammonium nitrogen by anaerobic fermentative bacteria. The ammonium form is subsequently retained by the clay particles in sediment by an exchange reaction. This retention slows nitrogen mobility from a watershed to receiving water bodies. Under high reducing conditions, nitrates may also be lost from the transporting streams as nitrites by the process of denitrification. Sometimes nitrogen content in the streams may also be buffered through fixation by blue-green algae.

VIKING

In watersheds where the streams have calcite at the water surface, or are rich in oxides of iron and aluminum, and/or have kaolinitic clay minerals, P lag time due to P fixation by sediments is long.

As outlined above, a consideration of the "lag time" phenomenon underlines the fact that nonpoint source pollution control management practices may not result in an instantaneous improvement in the affected receiving waters. This delayed response may take from several years to a decade or more. However, the fact remains that a major reduction in a pollutant input to a water system will eventually result in a new and lower equilibrium level for the pollutant in the system (Logan, 1986). Although lag time can be predicted, it is safe to assume that changes in water quality occur slowly and it is necessary to monitor for a long time to measure these changes.

2.6.1 The Effect of Lag Time on BMP Effectiveness

The purpose of a BMP is to keep a potential pollutant out of a water body, either by controlling input of the pollutant at the source or by reducing or stopping its transport. The lag time from installation of a practice to its measurable effect on the affected water body, is primarily a function of the distance from the pollutant source to the water body and the degree the pollutant can be attenuated during transport.

VIKING

For example, source control of an industrial input of a heavy metal to a municipal sewer can be observed at the wastewater treatment plant within days because of the relatively short distance of travel and low potential for attenuation. Likewise, application of no-till practices to small plots has been shown in numerous research studies to immediately reduces soil and sediment-bound P losses. However, there are few if any cases of monitored reductions of P loads with no-till from areas much larger than field size because sediment can be deposited in swales, drainage ditches or the streambed; and increased streambank or bottom scour may compensate for sediment P reductions at the land surface.

The myriad of physical, chemical, and biological processes that can affect pollutant transport within a watershed have made it the least understood component of the transport system, and there are presently no models that can fully simulate or predict these processes. In addition, year-to-year variations in climatic conditions and runoff can often exceed even the calculated reductions that could be obtained with land treatment. Because of these inherent variations and the attenuation of pollutants in watershed systems, it is expected that watersheds will not markedly respond to nonpoint source pollution reductions in periods shorter than 5 to 10 years. Even then, good monitoring programs coupled with good, long-term climatologic and hydrologic data and computer models that can account for year-to-year variability will be required before pollutant reductions can be quantitatively measured.

3.0 AGRICULTURAL BEST MANAGEMENT PRACTICES

Increased productivity in agriculture has resulted from scientific research leading to the application of new and improved technologies such as improved tillage and cultivating practices, and increased use of fertilizers, pesticides, and other agricultural chemicals. However, while these technologies have contributed to the development of "Industrialized Agriculture," they have also aroused public concern since their application may cause detrimental environmental effects. During storm events and/or snowmelt, runoff from the land surface carries sediments, pathogens, sediment-absorbed chemicals, dissolved chemicals such as nutrients and pesticides, heavy metals, and easily oxidizable organics into waterways.

EPA supports the use of Best Management Practices. BMP's defined in the Code of Federal Regulations (CFR 130.2, Title 40), as a key to source control management, and a wide array of practices, including crop management methods, is available to control various types of pollutants and nonpoint contamination problems (Table 4).

> A "Best Management Practice" is determined by a state (or designated area-wide planning agency) after problem assessment, examination of alternative practices and appropriate public participation to be the most effective practicable (including technological, economic and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals (C.F.R. 130.2, Title 40).

VIKING

To use BMP's, effectively it is important to understand the nonpoint source pollution problem. The problem must be properly defined and understood, and viewed in light of legislative mandates and the related environmental laws. All variables involved must be properly weighed, since failure to consider one or another can lead to the real or perceived problem of substituting one environmental problem for another. From an array of management practices, a system of BMP's adapted to specific site conditions, rather than uniform national or regional requirements, must be developed. In addition, the specific BMP or combination of BMP's selected must be the most economical choice for achieving water quality goals. The overall goal is to impose an environmental strategy comprising a mix of physical methods, implementation incentives, and institutional arrangements to provide NPS pollution control. Moreover, the performance indicators must be carefully monitored to see if the strategy is working or requires changes.

VIKING

Table 4 Crop Management Methods

A. Crop Management

1. Tillage
   - o Conventional plow, o Timing--fall, spring
   - o Chisel plowing o Conservation--tillage
2. Crop Sequencing (Eg., Mono-cropping,)
3. Seed/Plant Improvement (e.g., Salt tolerance)

B. Soil/Water Management

1. Runoff and Erosion Controls (such as countoring, Cover Crops etc.,)
2. Moisture Conservation Practices (e.g., fallow cropping)
3. Wind Erosion Controls, such as Windbreaks.

C. Nutrient Management

o Formulation o Species o Application methods

D. Pest Management

o Pesticides, including application methodology and Quantity

o Pest resistant crops o Integrated controls

o Cultural/mechanical o Biological controls

In using agricultural BMP's, management practices can be selected to control various types of pollutants. Practices that affect the physical system (e.g., tillage, structural controls), and land use influence erosion and runoff. Erosion is affected by changing slope, slope length, soil erodibility, and cover; runoff is affected by the those factors as well as soil infiltration capacity. Pollutants -- such as most pesticides, nitrogen and phosphorus, and easily oxidizable organics -- can be managed by controlling the application of these material, with respect to timing, concentration levels, chemical properties, and application methodologies. The timing or temporal management, of these controllable inputs is particularly crucial, and should consider such factors as:

- probability of a runoff event with respect to the application date, and the degradation or transformation behavior of the chemical;
- degree of soil cover;
- receptor (such as crop pest) life cycle stage at which the greatest impact can occur;
- flow stage, so that impacts on streams would be expected to be higher at low flows, if the chemical is expected to reach the stream.

Therefore, the "Best" management practices, from an environmental standpoint would:

- provide optimum soil cover, crop residues, canopy development, and/or soil surface roughness to dissipate raindrop impact and reduce runoff velocity;

- provide optimum soil infiltration and flow path to minimize erosion through soil detachment and transport, and reduce runoff volumes through enhanced infiltration periods of maximum runoff producing rainfall events;
- minimize or reduce soil losses and concentrations of nutrient soluble pesticides, etc.

Of the various BMP's being assessed in this study, conservation tillage in varying forms is the most widely applicable and used BMP. Conservation tillage also seems to have the greatest potential for wider nationwide application. For these reasons it is important to fully understand this BMP. Therefore, a greater emphasis on the definition, use,and effectiveness of this BMP has been given in this study.

VIKING

3.1 CONSERVATION TILLAGE

Conservation tillage has been defined by various authors to include such terms as "no-till", "minimum tillage", "reduced tillage", and "mulch tillage". Confusion therefore exists over the exact definition of conservation tillage. The most widely accepted definition, is given by the Conservation Glossary (1982), which defines conservation tillage as "any tillage system that reduces loss of soil or water relative to unridged or clear or conventional tillage." In general, conservation tillage practices consist of "reduced tillage" or "no tillage," which leave a protective mulch of crop residues at the soil surface and are often called conservation tillage systems.

The definition given by U.S. Department of Agriculture for conservation tillage and its various types is as follows:

Any tillage and planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion by water; or where soil erosion by wind is the primary concern, and maintains at least 1,000 pounds of flat small grain residue equivalent on the surface during the critical erosion period.

TYPES OF CONSERVATION TILLAGE

- No-till

  The soil is left undisturbed prior to planting. Planting is completed in a narrow seedbed approximately 1-3 inches wide. Weed control is accomplished primarily with herbicides.

- Ridge-till

  The soil is left undisturbed prior to planting. Approximately 1/3 of the soil surface is tilled at planting with sweeps or row cleaners. Planting is completed on ridges usually 4-6 inches higher than the row middles. Weed control is accomplished with a combination of herbicides and cultivation. Cultivation is used to rebuild ridges.

- Strip-till

  The soil is left undisturbed prior to planting. Approximately 1/3 of the soil surface is tilled at planting time. Tillage in the row may consist of a rototiller, in-row chisel, row clearners, etc. Weed control is accomplished with a combination of herbicides and cultivation.

- Mulch-till

  The total soil surface is disturbed by tillage prior to planting. Tillage tools such as chisels, field cultivators, discs, sweeps, or blades are used. Weed control is accomplished with a combination of herbicides and cultivation.

- Reduced-till

  Any other tillage and planting system that meets the 30 percent residue requirement.

Successful conservation tillage reduces soil and water losses by:

- leaving appreciable crop residue on the soil surface (retaining standing stubble is important in wind erosion control);
- leaving the surface rough, porous, cloddy, or ridged; or

- a combination of the two methods listed above.

To effectively use conservation tillage, a system must be selected that will adequately control soil erosion, conserve moisture, and accommodate crop grown. Equipment needs must be based on soil and climatic conditions. Weed, disease, and insect control chemicals, must be applied effectively and efficiently for sound environmental management and profitable crop yields.

Resources in conservation tillage include labor, machinery and equipment, fuel, fertilizers, pesticides, and management. Labor requirements are generally less for conservation tillage than for conventional tillage. However, estimates on labor savings using conservation tillage vary greatly. In case of equipment, most researchers agree that equipment costs are less with conservation tillage than with conventional tillage. Direct planting into untilled soil requires less power than conventional tillage (U.S. Senate, 1979, Wauchope et al. 1982).

Conservation tillage, because of fewer passes over the field, requires less preharvest fuel than conventional tillage. However, the energy advantage of conservation tillage is partially offset by the greater amount of energy resulting from increased herbicide and N fertilizer requirements, although due to paucity of data,

VIKING

generalizations are difficult.

In terms of pesticides and pest management, conservation tillage relies more on herbicides and less on cultivation to control weeds than conventional tillage. No-till systems, on the other hand, may rely completely on herbicides. Since herbicides usually do not attack the roots of plants, perennial weeds become more significant in fields using conservation tillage over time, and may make conservation tillage uneconomical.

There are several reasons why conservation tillage might require more pesticides and pest management. Among these are:

- since weeds are conventionally controlled by tillage, any reductions in this would require compensatory increases in other means, such as increased use of herbicides to maintain a given level of control;
- crop residues, resulting from conservation tillage tie up some of the herbicides; requiring larger amounts for weed control;
- increased moisture retention resulting from conservation tillage practices, not only benefit the crops, but also produce better conditions for germination and growth of weeds, thereby requiring greater herbicide usage.

3.1.1.1 Conservation Tillage and Crop Yields:

Because conservation tillage never causes more erosion than conventional tillage, the long-term effect of erosion on yields can never be to the disadvantage of conservation

VIKING

tillage. On level land, erosion is not a problem, so the choice between technologies is determined by other factors. Whether the erosion potential favors conservation tillage on more erosive soils depends upon: the erosion-induced difference in annual yields between the two technologies; the cost to the farmer of offsetting the yield loss with conventional tillage by substituting fertilizer or other inputs for the soil lost to erosion; the length of time over which the yield differences make a difference to the farmer; crop prices expected by the farmer relative to current prices; and the rate of discount the farmer applies to future earning. Little is known about these factors except that they all vary widely among farmers, and some (for example, price expectations) vary over time for any given farmer. It is, therefore, impossible to make firmly grounded generalizations about the strength of erosivity in farmer's choices between conservation tillage and conventional tillage, except that it will never work against conservation tillage.

Given the uncertainty about the effect of longterm yield differences on farmers' choices between the two tillage technologies, it is likely that the choice by most farmers will be influenced by short term differences. Evidence from both experimental plots and in farmers' fields, indicates that yield differences between the two technologies vary widely from place to place and over time;

VIKING

conservation tillage has the advantage in some instances and not in others. However, on well-drained soils, where weeds can be controlled by herbicides about as well as with cultivation, conservation tillage yields are fully competitive with yields for conventional tillage. On droughty soils or in areas where rainfall is a limiting factor, conservation tillage typically will give higher yields than conventional tillage. Moreover, the time-saving and soil moisture retention characteristics of conservation tillage permit double-cropping in areas where it is not economically feasible with conventional tillage. Finally, the two tillage systems may differ with respect to yield variability over time. This could influence the choice between the technologies for farmers not indifferent to risk.

3.1.2 Evaluation of Research Data

A review of literature indicates that more research has compared various conservation tillage practices with conventional tillage than has been done on any of the other BMP's. This is because conservation tillage seems to be one of the most effective BMP's for reducing soil erosion and runoff, and yields from conservation tillage are roughly equal to or better than conventional tillage (Gard, 1977).

Conservation tillage practices, by maintaining crop residue, provide increased infiltration and reduced runoff

VIKING

(Logan, 1981). In another study, Johnson et al. (1979), reported a reduction in runoff of 54 percent when no-till replaced conventional tillage for corn crops. Burwell et al. (1968) found that fall mulch-tilled fields in Minnesota (one pass with a chisel plow) previously cropped with oats provided nearly eight times greater infiltration capacity than conventional tilled fields before runoff began. Increased infiltration and reduced runoff volume resulting from conservation tillage practices have also been noted by several other investigators (Blevins et al. 1977; Edward, 1972; Harrold, 1972).

One of the most comprehensive studies designed to evaluate the effectiveness of conservation tillage in reducing agricultural runoff, was conducted by Langdale (1979), at the Watkinsville, Georgia, Experimental Station. Conservation tillage practices were studied over a 4-year period and included moldboard (conventional) plowing; fall moldboard plowing (conventional); spring chisel plowing; and no-till. The results indicated that the runoff was reduced by 47 percent between conventional tillage and no-till. Soil losses were also reduced by 81 percent with the chisel plow, and 98 percent with the no-till system.

Other studies have found considerable variation in the extent that minimum tillage and no-till systems reduce runoff. A study by Smith et al. (1979), found runoff slightly greater from conservation than from conventional

VIKING

tillage systems. Data showed that no-tillage runoff was 10 to 30 percent higher in three out of four years from corn fields. However, Logan and Forster (1982) concluded that no-till results in increased runoff, compared to conventional tillage, specifically in soils with poor internal drainage or restricted subsurface drainage. More permeable soils on the other hand, show significantly reduced runoff with no-till practices. In another study conducted at Arlington, Wisconsin (Andraski, 1983), simulated and natural rainfall were used to observe the impacts of tillage systems on runoff as well as soil loss. At high intensity, simulated rainfall reductions in runoff of 38, 21, and 23 percent were observed from chisel, till-plant and no-till systems, respectively. For lower rainfall intensity, the percent reductions in runoff were observed in the following order: no-till--56, 69 percent; till-plant--42, 68 percent; and chisel--38, 67 percent. Under natural rainfall, conservation tillage reduced runoff by 85 to 90 percent as compared to conventional tillage during the 2-year study period. The percent reductions of soil losses relative to conventional were: no tillage, 88 percent; till-plant, 70 percent; and chisel, 64 percent. Results of the other studies on soil loss reductions by various conservation tillage practices, are summarized in Table A-1 (Appendix A).

In summary, sediment loss in runoff from cropland appears directly related to practice and frequency of tillage. No-till, while showing the greatest reductions in soil loss (on the average almost 90 percent), appears to be best suited to warmer areas with well-drained soils, where higher yields can be achieved with less of an increase in the use of herbicides. Other conservation tillage systems (Table A-1 through A-4, Appendix A), result in 60 percent reduction of soil loss and crop production under cooler climates and more poorly-drained soils.

Regarding P, since the majority of the P is normally attached to sediment, erosion control practices show the promise of reducing the total phosphorus (TP) in runoff, and presumably, TP inputs to surface waters. Most runoff studies have emphasized soluble P and/or TP as indicators of the pollution potential of runoff. Recently conservation tillage methods have received considerable attention as management alternatives for reducing pollutant loads in agricultural runoff. Many of these practices have been shown to reduce erosion and as a result TP losses (Romkens et al. 1973). However, studies have also shown that soluble P concentrations and losses may be greater with conservation tillage (McDowell and McGregor, 1980). These researchers felt that higher concentrations of soluble P were primarily attributed to a lack of incorporation of fertilizer P and to a release of P from crop residue (Timmons et al. 1973).

VIKING

3.2 CONTOUR FARMING

Contour farming, is farming gently sloping land (usually 8 percent or less), so that plowing and cultivation are done on the contour. The land should be free of depressions and gullies to encourage greater infiltration and reduce runoff volume. Water is also held on the field by contouring when row crops are ridged and furrowed rather than "flat" planted (USDA-SCS, 1980).

Contouring reduces sediment losses by reducing the volume of runoff and by slowing down water movement. Contour furrows catch and hold water during rainstorms, reduce runoff velocity and thereby increase both the time for infiltration and the soil's moisture content.

Contouring generally is more effective in reducing runoff on permeable soils rather than soil with high clay content (Baver et al. 1972). A study conducted in west central Iowa measured a 55 percent reduction in runoff volume from contoured plots (Saxton et al. 1968). Various other studies, including Johnson et al. (1978), report reductions in runoff volumes of 15 to 55 per cent by contour farming depending on type of soil and crop grown.

Some studies have reported a potential for increased crop yields from contour farming compared with uncontoured farming. This may be due to reduced soil and nutrient losses, as well as increased moisture availability.

Stallings (1945), reviewed 30 different sites and reported 17 percent average crop yield increases with contour farming. However, in areas with excess rainfall and poorly-drained soils, crop yield reductions can be expected. Onstad (1972), in studies conducted in Madison, South Dakota found about 3 percent increase in corn yields on contoured versus uncontoured plots. Wright et al. (1978), used contour farming on semiarid Montana rangeland and found significant increases in forage production, with corresponding decreases in rangeland erosion. A similar study (Branson et al. 1966), conducted in Montana and Wyoming, reported 118/136 percent increase in forage yields.

Soil loss reductions resulting from contour farming were also reported by various researchers (Burwell et al. 1975; Alberts et al. 1978). Study results of other researchers are shown in Tables A-1 to A-4 of appendix A.

While rainfall patterns and soil types are important factors in determining the effectiveness of contour farming in controlling soil losses, slope and length are the most critical factors. As pointed out earlier, contour farming is only effective on moderate slopes (8 percent or less). Length of slope becomes critical when rainfall exceeds infiltration rates. In large storms, break-over of contours can occur, due to the great volume of runoff moving on longer slopes.

VIKING

In summary, soil loss reductions with contour farming in the range of 40 to 60 percent can be expected (Tables A-1 to A-4, Appendix A). In the Great Lakes Basin, the International Joint Commission on Water Quality concluded that contour farming can reduce soil losses by 50 percent or more. As a BMP, it can be used best in combination with diversion on terraces, in order to reduce length of the slope. In the United States, Florida is the only state where it can not be practiced widely. However, literature contains little information on the use of contour farming as an agricultural BMP.

VIKING

3.3 COVER CROPS

Cover cropping is a BMP, which is employed to reduce the volume of runoff and lessen soil detachment from raindrop impact, outside the growing season. This practice involves the planting of close-growing grasses, legumes, or small grain crops, grown primarily for seasonal soil protection and for conservation tillage residue (USDA-SCS, 1980). For example, cover crops improve soil structure, enhancing runoff infiltration and reducing the loss of fertilizers and applied chemicals. There is also evidence that non-legume cover crops, as a result of plant uptake, may reduce nitrate leaching to the groundwater (Stewart et al. 1975). Cover crops are being widely adopted both as a sediment reducing and soil fertility building practice. In warmer areas of the United States where legume crops can be established over winter, nitrogen fertilizer requirements can be reduced significantly (Mitchell and William, 1977). Large-scale studies on the Black Creek watershed in Indiana have established that cover crops reduce erosion (Morrison, 1977). A recent Missouri study found rye cover crops reduce soil losses by over 95 percent, compared to conventional tillage of continuously cropped corn.

Successful use of cover crops in controlling nonpoint pollution depends on the availability of water. For example, when rainfall patterns are favorable, use of winter wheat as a cover crop is feasible. The stubble of winter-

VIKING

grown wheat until recently, was burned in most of the South, before double cropping to soybean or sorghum.

The effect of winter cover crops on the yield of succeeding row crops depends upon climate and soil moisture. (Stewart et al. 1975). In warmer areas under excessively wet spring conditions, cover crops can increase the soil drying rate through transpiration, allowing more timely planting and possibly increased yields. Counteracting the transpiration process, however, is the fact that the cover crop (to various extents depending on soil, climate and other conditions), will delay warming of the soil in spring. This slows the drying of the soil, by evaporation. This can be the overriding consideration in northern regions of the United States, where planting must be done as early as possible to maximize yields. In northern regions, small amounts of the cover crop will grow in the fall, and the spring transpiration rate will be less than in southern regions where the longer growing season and warmer temperatures allow more plant growth before winter. For these reasons, cover crops are not recommended as a BMP in Vermont and northern lake states. Other erosion-reducing practices, such as certain reduced tillage practices probably allow an improved balance between production and water quality goals.

VIKING

3.4 CROP ROTATION

Crop rotation, refers to a crop management technique, aimed at maintaining the productive capacity of soil by growing different crops in succession, to protect soil and replenish crop nutrients. Using a legume in rotation with other crops, is commonly practiced to improve the nitrogen content of soils.

Rotating row crops with sod crops is a standard recommended BMP for reducing soil erosion. Rotations that include a sod crop can reduce erosion losses from 40 to 90 percent as compared to leaving the field bare. It can increase organic matter and infiltration, and improve yields of cash crops (Humenik et al. 1982). Research has shown that closely sown sod crops result in significantly less runoff than row crops. Use of a sod crop, compared to continuously cropped corn, reduced soil losses by as much as 80 percent (USDA, 1976); although Laflin, and Moldenhaur, (1979), found no difference in soil losses between corn-soybean and soybean-corn rotations. When a cash crop is not included in a rotation, the economic loss can reduce the acceptability of this BMP.

The biophysical mechanisms, responsible for reducing the runoff and sediment load by inclusion of sod forming crops in rotation, are attributed to the following:

- sod crops protect the soil from raindrop impact by dissipating the raindrop energy, either intercepting the drop prior to its impact on soil particles or breaking it into smaller drops.

- soil structure improvement, due to the addition of soil organic matter by fibrous root systems of sod crops, results in increased infiltration rates.
- the presence of polysaccharides in sod soil organic matter fosters the development of crumb structures and water-stable aggregates. Differences in water-stable aggregates account for 69 percent of variance in infiltration and 71 percent of variance in soil loss (USDA, 1976).

Kramer et al. (1980), when comparing continuous corn rotation with a 4-year corn-wheat-pasture, indicated that over 90 percent of the soil losses from a 4-year rotation occured during the years the plots were under corn. The soil loss from corn in crop rotation was only about 70 percent of that for the continuous corn, even though both were grown under conventional tillage.

In addition to the role of sod crops in rotation, the literature also documents to some extent the potential environmental effects of crop sequence from a particular site. For example, Van Doren et al. (1984), showed that in a corn-soybean rotation, a soybean crop apparently predisposes a field to greater erosion by water than corn. McGregor et al. (1982), showed that soil losses following soybean ranged from 43 to 70 percent greater than those following corn. Research reports showing previous years crops having no effect on erosion are much fewer. The greater soil losses after soybeans have been attributed to a less stable soil

VIKING

Table 5 Effect of Crop Sequence and Duration of Sod Crop in Crop Rotation on Infiltration and Soil Loss from a Loam Soil with 5 percent Slope (Mannering and Myer, 1961).

Total Infiltration and Soil Loss, (After Planting, After first Cultivation, and After Harvest)

Treatment	Infiltration of Rainfall (cm)	Soil Loss (metric ton/ha)
Fallow	16.38	97.04
5 yrs. continuous corn	18.57	71.56
3rd yr corn, 2 yrs meadow	19.30	64.23
2nd yr corn, 2 yrs meadow	21.62	54.12
1st yr corn, 2 yrs meadow	24.54	40.25
1st yr corn, 1 yr meadow	20.88	59.61
1st yr corn, 3 yrs meadow	24.46	35.50

Total Infiltration & Loss During Two Crop Stages--After Planting & After 1st Cultivation.

Treatment	Infiltration of Rainfall (cm)	Soil Loss (metric ton/ha)
Fallow	8.56	124.78
6 yrs continuous corn	8.31	85.02
4th yr corn, 2 yrs meadow	9.30	82.63
3rd yr corn, 2 yrs meadow	10.29	74.71
2nd yr corn, 2 yrs meadow	10.11	64.92
2nd yr corn, 1 yr meadow	8.26	95.09
2nd yr corn, 3 yrs meadow	10.87	76.24

VIKING

surface and smaller amounts of residue. Browing et al. (1949), found that soil under row cropped soybeans was comparable in penetratability to soil covered with burlap, and had a lower penetration force than soil under corn. These researchers believed that the soybean canopy acts by intercepting and dissipating the raindrops, thereby, preventing the compaction of soil surface.

For minimizing nonpoint pollution, it is not only the inclusion of sod crops but the also relative sequence of sod and row crops in rotation that is important, since it affects infiltration and erosion. Understanding the effects of various crop sequences on soil and physical properties influencing surface runoff and sediment transport, is important. Most data on crop rotation relates to effects on soil fertility and crop yields, with very little, or no emphasis on soil conservation and water quality.

VIKING

3.5 TREE BARRIERS

Tree barriers can effectively bind soils to reduce sediment loads entering water bodies. Tree barriers are also effective in reducing the wind velocity and controlling wind and soil erosion.

The maintenance of tree barriers along stream banks has been reported to lower water temperatures. Temperature is an important factor in regulating chemical and biochemical transformations in the nutrient load of stream waters. One study found weekly maximum temperatures of forested streams to be 5.0 to 12.6 degrees below the temperatures of streams in open areas (Omernik et al.1981).

Based on the examination of temperatures in various streams bordered by shrubs or trees, the following generalizations can be made:

- effectiveness of tree barriers decreases with increasing stream width;
- vegetation width is unimportant;
- angular canopy density of tree barriers (a measure of shading ability of vegetation) is the only vegetation parameter that has direct correlation with temperature (Musgrave, 1947).

3.5.1 Effect of Tree Barriers on Runoff Nutrient Loads

As water temperature increases, the water's oxygen capacity decreases. At elevated temperatures the ability of the sediments to reduce bioavailable nutrient loads is reduced. Temperature increases also increase the rate at which nutrients attached to suspended solids are converted to readily available (soluble) forms (Logan, 1986).

In addition, because of the exponential increase in P conversion to available forms with increasing temperature, slight increases in temperatures above 15 ^{0}C produce substantial increases in the amount of phosphorus released. At higher temperatures reduction processes reduce Fe (III) oxides and hydroxides of iron to Fe (II). This reduction of iron results in lowering the capacity of the suspended sediments to bind phosphorus in biologically unavailable forms. Moreover, increased temperatures further compound the deterioration of water quality, by lowering the critical limit for algal-available phosphorus. Borchardt and Azad (1968) found that the critical solution PO_4 concentration required for maximal algae growth decreased linearly with increasing temperature from 10°C to 30°C. They concluded that this may well explain the sudden blooming of plankton after a warm spring day.

Temperature reducing effects of tree barriers may also reduce soluble (nitrate), nitrogen contents of runoff waters. The water temperature increase leads to accelerated rates of conversion from NH_4^+ to NO_3^-. It has been shown that with each 10 ^{o}F increase in temperature, nitrification rates in sediment water systems doubled. Thus, the presence of tree barriers along stream banks helps

VIKING

keep nitrogen in bio-unavailable forms, by reducing the oxidation of organic and NH_4 nitrogen to nitrates.

3.5.2 Effect of Tree Barriers on Runoff Sediment Loads

The presence of tree barriers along a stream has been shown to reduce the sediment load to the stream. This reduction in sediment load occurs due to:

- decrease in the capacity of raindrops for soil detachment in the presence of a surface cover of leaf litter;
- presence of surface leaf litter also acts as a sieving mechanism for entrapping suspended sediments;
- increased surface roughness in woodlots increases the amount of energy required to transport soil sediments; and
- reduced stream bank erosion.

3.5.3 Conclusions on Tree Barriers as an Agricultural BMP

Research on the use of tree barriers in reducing nonpoint pollution suggests the following conclusions.

- the presence of tree barriers along stream banks can reduce nutrient and sediment transport from terrestrial to aquatic components of ecosystems.
- buffer (tree) strips can be used to reduce temperature associated water quality problems in an agricultural watershed. This can be done by growing a narrow strip of trees to shade the traversing agricultural lands.

VIKING

- reduced soil temperatures will improve the quality of stream water by helping to maintain plant nutrients N and P in biologically unavailable forms.

- when stream water has a lower temperature than the temperature of a receiving lake, the water will be discharged into a deeper zone. Soil sediments will then be deposited where (given the lower temperatures and ambient conditions), they may not release their nutrients.

- the presence of tree barriers along the stream bank provides surface roughness that reduces sediment load. In addition, the presence of nearstream vegetation (sometimes assisted by tree barriers), reduces stream bank erosion.

Tree barriers, like vegetative strips, can effectively filter sediment loads entering water bodies. However, review of the literature reveals that very limited research has been done so far on tree barriers. In the absence of meaningful field data, it is not possible to establish the effectiveness of this practice as an agricultural BMP.

3.6 COMPARATIVE ASSESSMENT OF VARIOUS BMP's

Based on the results of various research studies summarized in Tables A 1 to A 4 (appendix A), and discussed above, the following conclusions regarding the five BMP's considered can be made:

- the overall profitability of conservation tillage (the most widely used BMP), depends primarily on the effects of yield. If yields are effected slightly or not at all, conservation tillage systems are generally more profitable and enhance water quality.
- conservation tillage systems are capable of reducing soil losses 60 to 90 percent, as compared to conventional tillage, regardless of geographic area, soil type, slope, climate, or type of crop grown.
- considering all other factors as equal, the extent of soil loss reduction is a function of the amount of tillage performed. No-till systems will reduce soil loss more than reduced tillage systems.
- conservation tillage practices compared to conventional tillage systems, also result in higher crop yields, on well drained soils and in dry years. However, this does not apply to poorly drained soils or during high rainfall years.
- soil conservation practices such as residue management and sod-based rotations, can decrease total and soluble P losses in surface runoff.
- no-till systems are more suitable for warmer climates. In cooler regions slow soil warming results in yield reductions from delayed planting.
- crop rotation, no-till, and conservation tillage may reduce N losses in surface runoff.
- contour farming on sloping croplands can reduce soil losses from 60 to 80 percent, as compared with non-contour farming is generally effective on 8 percent slopes or less; and being highly site-specific, effectiveness of contouring varies with such factors as types of tillage and land slopes.

VIKING

Other irregularities related to row slopes, row lengths, row widths, cropping systems, and rainstorm patterns also significantly influence its effectiveness.

- contour farming can reduce total P losses by limiting sediment and water runoff.
- crop yields with contour farming may be higher under dry conditions, and lower under excess moisture or poorly drained soil.
- cover crops can be an effective BMP for all soil types in warm geographical regions. Applicability in colder regions is limited due to the difficulty of establishing significant plant growth; and the use of cover crops can delay soil warming/drying in springtime, and affect crop yields.
- crop rotation can reduce soil losses significantly, but more research is needed before any conclusion can be drawn regarding its effectiveness. Unless a cash crop can be included in a rotation, its acceptability may be limited.
- crop yields with grasses and legumes in rotation, will likely be higher.
- rotation of sod and row crops can reduce erosion 80 percent in sod crop years and provide carryover effects when row crops are planted.
- tree barriers can be an effective BMP in reducing soil losses and sediment nitrates, but currently very limited data on P load reductions and the role of tree barriers as an agricultural BMP exists.
- some amount of trade-off between sedimentation and associated nutrient transport, and leaching of nutriments to groundwater may be inherent in practices such as conservation tillage and contouring which reduce erosion but increase infiltration and percolation.
- because a specific BMP can be effective in reducing soil loss on its own or in combination with another BMP, combinations of two or more types of BMP's will undoubtedly provide the best soil loss reduction and water quality improvement strategies.

4.0 BMP OPTIMIZATION AND EFFECTIVENESS

Appropriateness of a given BMP to physically control pollution movement in a field, should reflect the extent to which the BMP:

- reduces the amount of pollutant made available for transport;
- partitions water flow between overland flow and subsurface flow; and
- manipulates the transformations of the pollutant during transport flow.

Control measures affect pollutant yield to streams through three basic mechanisms: availability, detachment, and transport. As a first step in the BMP selection process, the pollutant of interest is classified as soluble, adsorbed or precipitated. The physical and chemical association of the pollutant with sediments will determine, to a great extent, which particular BMP would be an effective control measure. Few practices are effective in controlling all potential agricultural pollutants.

To determine whether a practice effectively controls a specific pollutant, it is necessary to determine both the pathways, and the overlying physical variables, providing sufficient energy to detach and transport a pollutant from cropland to other water bodies. Experience has shown that cultural and farm management practices reduce erosion and sedimentation more efficiently, than the use of runoff collection and disposal practices.

VIKING

4.1 SYSTEM'S OPTIMIZATION

Any evaluation of BMP's for nutrient control (specifically N and P), from agricultural land must simultaneously consider the impact of the BMP's on both surface and groundwater, the transport or loss of both nutrients, the technical feasibility, the economic viability, and the farmer's acceptability of the BMP's. Too often in the past we have only considered the absolute effectiveness of the practice to control a single pollutant (or even a single form of the pollutant), being discharged to a single water source. Failure to consider one over the other variables, can lead to the real or perceived situations of substituting one environmental problem for another. The following examples illustrate this:

- the use of no-till on permeable soils to reduce runoff and loss of P to surface water can result in greater infiltration and potential contamination of groundwater by nitrate if N fertilizer management is not also considered;
- expenditure of public cost sharing funds for construction of manure storage facilities will have little or even negative environmental impact, if farmers have inadequate land for utilization of manure or if it is inappropriately applied; and
- farmers using no-till on grain land to control erosion and P losses to surface water may actually increase P losses, if manure is applied without injection to no-till land on soils with low infiltration or under water-saturated conditions.

VIKING

To avoid these problems, a system's approach must be used which first identifies the primary source of pollution and the affected water body. Potential BMP's to control movement of specific pollutant(s) to water bodies are identified and screened for secondary environmental impacts to both surface and groundwater. Finally, the economic viability of the selected practice must consider farmer's acceptability. Farmers tend to accept practices that least affect their day-to-day farm management and involve small capital investment and low economic risk. One such practice would be a partial reduction of P fertilizer use on high P soils. One-time installations of structural practices such as terrace or sediment detention ponds, may also be acceptable if cost-sharing is available. Changes in management such as a shift from plowing to no-till or a change in crop rotation will be accepted only if clearly demonstrated to be in the farmer's best economic interests.

A conservation plan for a farm must, therefore, simultaneously consider:

- potential pollutants;
- affected water bodies;
- technically feasible BMP's;
- economic viability of BMP's; and
- farmer acceptance.

VIKING

4.2 WATERSHED APPROACH

A watershed approach is the only meaningful way to deal with nonpoint problems. The watershed is defined as the drainage area above the waterbody of interest (for example, a lake or stream reach). This approach identifies, on a distributed basis, all pollutant sources and routes with appropriate transport models to the waterbody. BMP's, then are imposed on these sources and the reductions measured by monitoring or calculated by use of a watershed model.

The watershed approach requires some kind of geographical information system, by which pollutant sources can be physically distributed and the appropriate model used. A simple desk top model which can be used for initial planning is given by Sonzogni et al. (1980).

Early watershed research, to evaluate the effects of land use treatments on rainfall runoff relationships, used standard statistical analysis for evaluation. Paired watershed and before-and-after treatments were also used. In cases where the treatment effects were large, the analysis were able to detect and evaluate their significance.

However, in many cases, the differences among study plots significantly masked the treatment effects being evaluated. In other cases, climatic differences between periods masked the effects. Mathematical and hydrologic

VIKING

models can be useful in watershed research. These models can: (1) structure date collection, (2) predict site response, (3) select and evaluate parameters, (4) determine the accuracy used in evaluating input variables and parameters, (5) study the significance of spatial and temporal variability of physical features, and (6) determine observations needed to achieve a given degree of accuracy in a specified period of time (DeCoursey, 1985).

Many models have been developed that concentrate primarily on sediment transport (Knisel, 1980). Several of these have a good hydrologic model as a base. The Areal Nonpoint Source Watershed Environment Response Simulation (ANSWER), model is one example of a good stochastic model that can be used to study the effects of land management on soil erosion and sediment (Beasley et al. 1980). The "ANSWERS" model can be used within the "hot spots" to pinpoint critical areas needing treatment. Notably, the model can predict how extensive treatment is required to achieve predetermined water quality goals. For larger basins, a similar model -- Precipitation, Runoff Modeling System (PRMS), developed by U.S. Geologic Survey can be used. Strong points of PRM are the snowmelt and channel hydraulics components for estimating flood peaks (DeCoursey, 1985).

With respect to nonpoint sources of pollution, only one model, Chemicals Runoff and Erosion from Agricultural

VIKING

Management Systems (CREAMS), has been developed specifically to simulate the response of a field-size area. CREAMS consists of several options, from rather simple daily methods to more complex infiltration based schemes, to simulate tillage, crop growth, erosion, sediment yield, and plant nutrient and pesticide movements. The CREAMS model has been used successfully on a large number of field-scale agricultural sites to evaluate alternative land use practices and conservation measures. A new version of the model that is more comprehensive and expands considerably on model assessment capabilities is nearing completion (DeCoursey, 1984).

The Nitrogen, Tillage, Residue Management Model (NTRM), was developed for nitrogen, tillage, and crop residue management. Because of its physically based conceptual structure, NTRM is also useful in watershed research. The model integrates hydrologic cycle that occurs in soil and nutrient submodels. It has the capability of making seasonal and long-term estimates of soil fertility and fertility effects on crop yield.

Control of diffuse or nonpoint sources of water pollution poses several fundamental research questions that are only partially answered, with tremendous implications for success of land management techniques to reduce soil-associated pollutants. Foremost is the question of identifying source areas. Classic soil erosion theory and

VIKING

test plot data both establish that: in areas otherwise equal, more steeply sloped areas, usually basin headwaters, will contribute more erosion. BMP's should, therefore, be directed toward certain slopes--defined "hot spots" in the watershed. For example, the Black Creek Project Studies indicated that treating only 80 acres of the most highly erosive areas in that basin of 1800 acres would reduce the total sediment load by 40 percent. The costs of control could be minimized -- if these 80 acres were treated rather than 1800 acres; the cost would be $6000 rather than the $135,000 which would be required to treat the 1800 acres (Groszyk, 1978). Moreover, the ability to target efforts on "hot spots" rather than applying identical control measures over broad areas of land, means that planners and farmers can maximize the effectiveness of BMP's to control nonpoint water pollution. Use of water quality models such as "ANSWERS" or a similar model for this purpose is recommended. Statistical models will enable the identification of areas within planning regions where erosion and sediment problems can be anticipated.

Questions of sediment transport must also be considered. Does this material take many years to move out of a watershed, with subsequent scouring and deposition in temporary sinks--swales, ditches, and stream bottoms? Or does the majority of material observed in passage from a basin during a storm event, originate on the land surface during that storm? The answer will determine the selection of suitable land management techniques. The time sediment is in transport, the lag time, and other factors determine the time required to measure any success achieved by such alternatives as fertilizer reduction.

In addition to models, selection of BMP's has also been done using a combination of the Universal Soil Loss Equation (USLE) and the computer-based Land Resource Inventory System (LRIS). Evaluation of soil loss controls using these techniques under conservation tillage showed that a 40 percent reduction in sediment load is achievable. The maximum potential soil loss reduction was 69 percent when a combination of no-till and conservation tillage was used (Logan, 1986).

Another important aspect of the watershed approach relates to identifying source areas for implementing BMP's. This approach is based on partial area hydrologic theory. The theory suggests that overland flow occurs in only a limited portion of the basin, namely on soils directly contiguous to drainage areas. Accepting this determines a very specific management strategy. The main emphasis in controlling nonpoint pollution from agricultural soils, should be put on intensive use of BMP's on steep slopes and areas close to stream banks. If it is true, that most of the sediment being carried from an agricultural watershed comes from only 15 to 20 percent of the basin area, from areas of less permeable, poorly drained soils), then

VIKING

improved drainage and/or reduced cultivation, might have more positive effects than strategies which attempt basin wide to minimize rainfall's erosive energy by improved cover conditions, or to reduce velocity of overland flow by slope reduction (Logan, 1986). Morrison (1977), reported that ditch banks and stream channels produce a relatively small fraction (about 7 percent), of the total sediment load. The cost of dealing with this 7 percent has been high, both economically (about 30 percent of the land treatment project funds), and environmentally (Morrison, 1977).

Nonpoint modeling should contribute directly to the formulation of BMP strategies since this process must involve implicit or explicit tradeoffs between social costs and water quality benefits. BMP's need not be determined through an optimization process, but feedback between water quality effects and control alternatives is obviously desirable. Given the difficulties of maximizing water quality under management constraints, a reasonable procedure may be to establish the water quality constraints and then explore possible management strategies to achieve the chosen goals. This might be done by developing a series of scenarios, each consisting of a spatially detailed set of management practices, that are shown to yield acceptable pollutant loadings. Rather than choosing a "best" plan according to formal criteria, the scenarios could be submitted to policymakers, who could then examine the products of vigorous analysis and apply intuitive judgment.

5.0 CONCLUSION AND RECOMMENDATIONS

Based on this study, several conclusions regarding the "Best Management Practices" for controlling sediment, N, and P in runoff from agricultural lands can be made. These include:

- Erosion reduction on cropland is generally proportional to reductions in the amount of tillage performed. Conservation tillage systems can reduce soil losses from 60-90 percent compared to conventional tillage and are an effective alternative for areas where no-till is not well suited. Surface runoff from conservation tillage averages about 25 percent less than conventionally tilled fields.

- No-till is extremely effective in reducing erosion losses with reduction of 70-99 percent but is not adapted to all regions and requires higher managment than conventional tillage.

- Since 48 to 98 percent of nitrogen and 87 to 99.6 percent of phosphorus in surface runoff is bound to sediment, sediment control practices can reduce the input of N and P from nonpoint sources.

- Contour farming reduces runoff and sediment loads by 15 to 55 percent and 40 to 60 percent respectively. Soluble N and P losses are reduced by 15 to 55 percent. However, reduction in total P loss may not be comparable to reduction in sediment load. This is because the portion of soil lost through erosion as sediment has a higher content of P as compared to P content of soil in the field.

- "No-till" can significantly decrease soil losses on land previously under conventional tillage. However, while total partiuclate P will be greatly reduced, dissolved P due to lesser sediments in the runoff may even increase. Other reasons for higher P levels with no-till are the build-up of fertilizer P on no-till soils and the leaching of dissolved P from decaying plant residues. Under such conditions, other management practices particularly proper ferilizer use for controlling dissolved P, may be more useful.

- Cover crops reduce N and P loss by reducing soil erosion by 40 to 95 percent. Non-legume cover crops, due to their utilization of N for plant growth, reduce nitrate leaching to groundwater.

- Although little data is available, it appears that tree barriers or stream side vegetation, improve water quality by lowering the temperature of water in steams. These lower temperatures reduce bio-available P and N, because slight increases in stream water temperatures above 15 C produce substantial increase in the amunt of P released. Streamside vegetation also reduces the sediemnt load by protecting the soil from raindrop impact, by entrapping suspended sediments, and by reducing stream bank erosion.

Among the major recommendations are:

- While research has identified a number of BMPs for nonpoint source pollution controls, these must be integrated to consider all potential pollutants, impacted areas, feasibility, economics, and acceptability.

- To effectively implement various BMPs, a watershed approach to identify, on a distributed basis, all pollutant sources and routes using various transport models to a water body needs to be developed. BMPs can then be imposed on these sources and reductions measured by monitoring, or calculated by use of a runoff model.

- The effects of even large scale adoption of BMPs will not be seen at the watershed levels in periods less than 5-10 years due to the "lag time" between implementation and observable results. Demonstration of BMP

VIKING

effects at the watershed level can only be quantified by coupling long term monitoring with the use of hydrologic models to account for annual variations. These efforts should be concentrated in those project areas where a high degree of land treatment has been achieved and where there is at least a few years of pretreatment hydrology (land where enough monitoring data such as sediment load, etc. exists) and pollutant transport data.

- Experience so far has shown that state and local management of nonpoint source control is the key to achieving water quality objectives. Wisconsin and Vermont are the prime examples highlighting the success of such an approach. While planning, analysis and implementation can take place at the state level, development of control measures will require a coordinated effort on the part of all levels of government.

VIKING

5.1 FUTURE RESEARCH NEEDS

Much is now known about the sediments and types of nutrients washed from agricultural lands. However, except for conservation tillage as an agricultural BMP, little has been reported concerning the other agricultural BMP's. Furthermore, most of the research data is related to the Corn Belt (in the midwest).

To answer the more specific questions regarding the effectiveness of BMP's, it is necessary for other regions to perform systematic studies similar to the Corn Belt efforts. Long term comparisons are needed to assess the water quality benefits of implementing various BMP's and BMP systems. Research is needed to determine if soil or water conservation practices can simultaneously serve both soil conservation and water quality goals.

Important research needs focus on the following:

- identified BMP's for nonpoint source pollution control, must be integrated to consider all potential pollutants, impacted areas, feasibility, economics and farmer acceptability.
- field and modeling studies to explore the transport of pollutants from field to stream (or aquifer) and the subsequent fate are needed.
- very little field information on sediment delivery ratios critical to sediment, and NPS pollution control measures is available.
- very little information currently exists on the actual water quality effects of the various

proposed BMP's. Most studies have centered on erosion reductions attributable to BMP's rather than downstream water quality changes.

- experimental as well as simulation techniques need to be developed, to predict the lag time between installation of a BMP, and its measurable effect on the affected water body.
- except for conservation tillage, there is an acute paucity of information on other agricultural BMP's. This is particularly true for tree barriers, crop rotation and cover crops.

VIKING

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TABLE A-1 DATA SUMMARY: REDUCTION IN SEDIMENT LOSS BY CONSERVATION TILLAGE

Page # 1

	STUDY NAME/ LOCATION	STUDY TYPE	TOTAL STUDY AREA, ACRES	GRADE OF SLOPE %	CONVENTIONAL TILLAGE		CONSERVATION TILLAGE (CT)		% REDUCTION IN SEDIMENT LOSS DUE TO (CT)	COMMENTS	REFERENCES
					CROP	SOIL LOSS TONS/ACRE	PRACTICE	SOIL LOSS	SOIL LOSS		
1.	Lake Erie Basin, Michigan	LRIS-Computer Model	3.4 x 10^6	35	Corn & Soybean	2.2	Reduced Tillage	1.3	40	LRIS is a variable size (9.8 to 90 acres size) computer based system.	Logan, 1982
					Corn & Soybean	2.2	No Tillage	0.7	69		
2.	Kingdom City, Missouri	Field	-	-	Corn	-	-	-	58	-	Burwell and Kramer, 1983.
3.	Western Corn Belt	Field	-	4	Soybean	-	No Tillage	5.36	-	-	Moldenhauer, et al., 1983.
4.	Western Corn Belt	Field	-	-	Corn	-	Chisel (up-down-slope)	12.12	-	-	
						-	Plow	16.0	-	-	
						-	No till	0.96	-	-	Moldenhauer, et al., 1983.
							Chisel (up-down-slope)	6.00	-	-	
5.	Milau, Tennessee	Field	-	-	Soybean	24.8	Plow	8.72	-		
							No-Tillage	0.32	99	Single-crop soybeans with no winer cover.	Moldenhauer, et al., 1983.
6.	Clark County, Kentucky	Field	-	-	Corn	0.92	Chisel plow and disk	0.12	87	-	Moldenhauer, et al., 1983.
						0.92	Disk	Trace	95^+		
7.	Lake Erie Basin, Michigan	ANSWERS_ Computer Model	4,500	-		0.92	No-Tillage	0	100	-	
						-	No-Tillage	-	80^+	-	Beasley, et al., 1985.
8.	Kentucky Agricultural Experiment Station, Lexington.	Field	-	5		8.06	No-Tillage	0.98	88	-	Frye, et al., 1985.

TABLE A-1 DATA SUMMARY: REDUCTION IN SEDIMENT LOSS BY CONSERVATION TILLAGE

STUDY NAME/ LOCATION	STUDY TYPE	TOTAL STUDY AREA, ACRES	GRADE OF SLOPE %	CONVENTIONAL TILLAGE		CONSERVATION TILLAGE (CT)		% REDUCTION IN SEDIMENT LOSS DUE TO (CT) SOIL LOSS	COMMENTS	REFERENCES
				CROP	SOIL LOSS TONS/ACRE	PRACTICE	SOIL LOSS			
9. University of Wisconsin, Madison, Wisconsin	Simulated	-	-	Corn	-	Chisel	-	64	-	Andraski, 1983
						Till Plant	-			
						No till	-			
10. Madison, South Dakota	Field	0.02	5.8	Corn	2.69	Till plant	1.57	42	Conservation tillage resulted in 7.2% increase in crop yield or 4.2 bu/acre.	Onstad, 1972.
11. Bedford, Indiana	Simulated	0.02	-	Corn	9.2	Coulter	0.69	93	-	Romkens,et al., 1973,
					9.2	Chisel	0.43	95	-	
					9.2	Double disk	1.35	85	-	
					9.2	Till	3.03	67	-	
12. Southeastern Iowa Conservation Tillage Research Project, Iowa	Field	432	-	Corn	-	Reduced tillage	-	-	Yield by conventional tillage, 4.4 tons/acre. Reduced yield by conservational tillage, 1.24 tons/acre. Reduced tillage resulted in 2% increase in crop yield or 4.5 tons/acre. However, no till resulted in 5% decrease in crop yield or 4.2 ton tons/acre.	Cruse,et al., 1983
						No-till	-	-		
				Soybean	-	Reduced tillage	-	-		
						No-till	-	-		

TABLE A-1 (Contd) DATA SUMMARY: REDUCTION IN SEDIMENT LOSS BY CONSERVATION TILLAGE

STUDY NAME/ LOCATION	STUDY TYPE	TOTAL STUDY AREA, ACRES	GRADE OF SLOPE %	CONVENTIONAL TILLAGE		CONSERVATION TILLAGE (CT)		% REDUCTION IN SEDIMENT LOSS DUE TO (CT)	COMMENTS	REFERENCES
				CROP	SOIL LOSS TONS/ACRE	PRACTICE	SOIL LOSS	SOIL LOSS		
13. Northeast, Indiana	Field	-	0.5	Corn	2.6	No-till	0.5	80	Hoytville silty	Mannering, et al., 1975
					2.6	Disk	0.4	85	Clay soil	
					2.6	Chisel	0.7	73	Clay soil	
					2.6	Plow	1.7	35	Clay soil	
				Corn	13.8	No-till	1.0	93	Mosley clay loam	
					13.8	Disk	1.0	93	Mosley clay loam	
					13.8	Chisel	6.0	57	Mosley clay loam	
					13.8	Plow	8.7	37	Mosley clay loam	
14. West Bend, Wisconsin	Simu-lated	-	4-6	Corn	2.4	Chisel	1.3	64	Without manure	Mueller, et al., 1984
						No-till	1.0	58	Without manure	
				Corn	2.2	Chisel	0.4	82	With manure	
						No-till	0.5	78	With manure	
15. Holly Springs, Mississippi	Field (plots)	0.022	7	Soybeans	7.8	No-till	0.8	0-		McGregor, et al., 1982
						No-till	2.3	71		
						No-till	1.1	86		
16. Holly Springs, Mississippi	Field (plots)	0.022	5	Soybeans	7.8	No-till	0.6	92	No till resulted in 46% increase in crop yield.	Mutchler & Greer, 1984
-do-						Reduced Tillage	3.2	59	Reduced tillage resulted in 12% increase in crop yield.	

TABLE A-1 (Cont'd) DATA SUMMARY: REDUCTION IN SEDIMENT LOSS BY CONSERVATION TILLAGE Page # 4

STUDY NAME/ LOCATION	STUDY TYPE	TOTAL STUDY AREA ACRES	GRADE OF SLOPE %	CONVENTIONAL TILLAGE		CONSERVATION TILLAGE (CT)		% REDUCTION IN SEDIMENT LOSS DUE TO (CT)	COMMENTS	REFERENCES
				CROP	SOIL LOSS TONS/ACRE	PRACTICE	SOIL LOSS	SOIL LOSS		
17. Holly Springs, Mississippi	Field (plots)	0.004	5	Corn	9.6	No-till*	0.3	97	No-till resulted in 18% increase in crop yield.	McGregor & Greer,et al., 1982.
				Corn	7.0	No-till**	0.3	96	No-till resulted in no change in crop yield.	
					7.0	Reduced-till**	0.6	91	Reduced tillage resulted in 11% increase in crop yield.	
18. Holly Springs, Mississippi	Field (plots)	0.004	5	Soybeans	11.8	No-till	0.1	98		McDowell & McGregor, 1980.
19. Holly Springs, Mississippi	Field (Plots)	0.004	5	Corn Corn	9.6 7.0	No-till* Reduced-till** No-till**	0.3 0.6 0.3	97 93 96		McDowell & McGregor, 1980.
20. Defiance Conservation District, Ohio	-	-	1.3	Corn	5.6	Reduced-till No-till	2.3 1.0	59 82	No-till resulted in 7% decrease in crop yield.	Defiance Conservation District, 1984.
21. Ohio		-	-	Corn	22.7	No-till	0.03	99		Harrold, 1972
22. Ohio	-	-	-	Corn	-	No-till	-	-	No-till resulted in 10% increase in crop yield.	Griffith, et al., 1977.
23. Indiana	-	-	-	Soybeans	-	No-till	-	-	No-till resulted in 21% increase in crop yield.	Doster, 1976.

*Corn for silage **Corn for grain

TABLE A-1 (Cont'd) DATA SUMMARY: REDUCTION IN SEDIMENT LOSS BY CONSERVATION TILLAGE

STUDY NAME/ LOCATION	STUDY TYPE	TOTAL STUDY AREA ACRES	GRADE OF SLOPE %	CONVENTIONAL TILLAGE		CONSERVATION TILLAGE (CT)		% REDUCTION IN SEDIMENT LOSS DUE TO (CT)	COMMENTS	REFERENCES
				CROP	SOIL LOSS TONS/ACRE	PRACTICE	SOIL LOSS			
24. Iowa	-	-	-	Corn	-	Till-plant	-	10	Till-plant resulted in 43% increase in crop yield.	Colvin, et al., 1983
				Soybeans	-	Till-plant	-	9	Till-plant resulted in 19% increase in crop yield.	
25. Iowa	-	-	5	Corn	36.9	No-till	10.5	72	No-till resulted in 5% decrease in farming cost for corn as well as soybeans.	Colvin, et al., 1983.
				Soybeans	30.1	No-till	12.3	59		
26. Missouri	-	-	3	Corn	12.5	Reduced-till	8.6	31	Reduced-till resulted in 2% decrease in farming cost.	Erwin, 1983
27. Iowa	-	-	1-4	Corn	5-15	Slot-till	1-2	93	Slot-till resulted in 1% increase in farming cost.	Jolly, et al., 1983
				Soybeans	3-12	Slot-till	0	100	Slot-till resulted in 2% increase in farming cost.	
28. Iowa	-	-	1-4	Corn	-	Chisel	-	-	Chisel plowing resulted in 13% decrease in crop yield.	Erbach, 1982.
						No-till	-	-	No-till resulted in 6% decrease in crop yield.	
						Chisel plow	-	-	Chisel plowing resulted in no change in crop yield.	
						No-till	-	-	No-till resulted in 4% decrease in crop yield.	

TABLE A-1 (Cont'd) REDUCTION IN SEDIMENT LOSS BY CONSERVATION TILLAGE

STUDY NAME/ LOCATION	STUDY TYPE	TOTAL STUDY AREA	GRADE OF SLOPE	CONVENTIONAL TILLAGE		CONSERVATION TILLAGE (CT)		% REDUCTION IN SEDIMENT LOSS DUE TO (CT)	COMMENTS	REFERENCES
				CROP	SOIL LOSS TONS/ACRE	PRACTICE	SOIL LOSS			
29. Ohio	-	-		Corn	6.9	Reduced-till	4.7	32	Reduced-till resulted in 6% reduction in farming cost.	U.S. Corps of Engineers, 1983.
						No-till	1.4	80	No-till resulted in 3% decrease in farming cost.	
30. Ohio	-	-		-	-	No-till	-	-		Logan & Forster, 1982.
31. Ohio	-	-	-	-	-	No-till	-	90		Logan,1981
32. M*	-	-	-	Corn	-	Till-plant	-	83		Butler, 1968.
33. P*	-	-	-	Corn	25.6	Chisel plow	4.8	81		Langdale, 1979.
					28.5	No-till	1.1	98		
34. M*	-	-	-	Corn	-	No-till	-	94		Mannering, et al., 1975.
					-	Chisel plow	-	60		
					-	Till-plant	-	85		
35. M*				Corn	-	Disk-chisel	-	89		Oschwald & Siemens, 1976.
					-	No-till	-	91		
				Soybeans	-	Disk chisel	-	71		
					-	No-till	-	85		

* SCS Land Resource Region (Fig. 1) - Appendix B

B - Northeastern wheat and Range Region
M - Central Feed Grains and Livestock Region
P - South Atlanic and Gulf Slope Cash Crops, Forest and Livestock Region

TABLE A-1 (Cont'd) DATA SUMMARY REDUCTION IN SEDIMENT LOSS BY CONSERVATION TILLAGE Page # 7

STUDY NAME/ LOCATION	STUDY TYPE	TOTAL STUDY AREA	GRADE OF SLOPE	CONVENTIONAL TILLAGE		CONSERVATION TILLAGE (CT)		% REDUCTION IN SEDIMENT LOSS DUE TO (CT)	COMMENTS	REFERENCES
				CROP	SOIL LOSS TONS/ACRE	PRACTICE	SOIL LOSS			
36. M*	-	-	-	Wheat	10.4	No-till	1.1	90	No till resulted in 14% decrease in crop yield.	Gard, 1977.
				Corn	1.0	No-till	0.04	98	No-till resulted in 73% increase in crop yield.	
37. B*	-	-	-	Wheat	23.2	Mulch-tillage	5.4	77		George, 1981.
38. M*	-	-	-	Corn Soybeans	- -	Till-plant till-plant	- -	60-90 -	Till-plant resulted in 3% increase in crop yield.	Ameniya, 1977.
39. M*	-	-	-	Corn	-	No-till	-	-		Forster, 1976.

*SCS Land Resource Region (Fig. 1) Appendix B

B - Northeastern wheat and Range Region
M - Central Feed Grains and Livestock Region
P - South Atlantic and Gulf Slope Cash Crops, Forest and Livestock Region

TABLE A-2 DATA SUMMARY: REDUCTION IN SEDIMENT LOSS BY CONTOUR FARMING

STUDY NAME/ LOCATION	TOTAL STUDY AREA ACRES	GRADE OF SLOPE %	UNCONTOURED/CONVENTIONAL FARMING		CONTOUR FARMING SOIL LOSS TONS/ACRE	% REDUCTION IN SEDIMENT LOSS DUE TO CONTOUR FARMING			COMMENTS	REFERENCE
			CROP	SOIL LOSS TONS/ACRE		SOIL LOSS	PHOSPHOROUS LOSS	NITROGEN LOSS		
1. Agronomy South Farm, Illinois Agricultural Experiment Station, Illinois	0.22	2	Corn	3.70	2.20	41	-	-	Contour farming resulted in 2.3% increase in crop yield.	Van Doren, et al., 1958
		2	Soybean	2.72	0.63	77	-	-	Contour farming resulted in 4.9% increase in crop yield.	
		2	Oats	0.80	0.50	38	-	-		
2. Madison, South Dakota	0.02	5.8	Corn	2.69	0.41	84	-	-	Contour farming resulted in 2.7% or 1.6 bu/acre increase in crop yield.	Onstad, 1972.
3. Indiana	-	2-5	Corn	4.0	0.9	78	74	-		
Indiana	-	2-5	Wheat	0.8	0.1	88	85	-		Bedell, et al., 1946.
4. -	-	2-8	-	-	-	50	35	-		International Joint Commission, 1983.
5. Illinois	-	-	-	-	-	-	-	-	Contour farming resulted in 11% increase in farming costs.	Lewis, 1985.
6. Indiana	-	-	-	-	-	-	-	-	Contour farming resulted in 2% increase in farming costs.	Lake and Morrison, 1977.

TABLE A-2 (Cont'd) DATA SUMMARY: REDUCTION IN SEDIMENT LOSS BY CONTOUR FARMING

STUDY NAME/ LOCATION	TOTAL STUDY AREA ACRES	GRADE OF SLOPE %	UNCONTOURED/CONVENTIONAL FARMING CROP	UNCONTOURED/CONVENTIONAL FARMING SOIL LOSS TONS/ACRE	CONTOUR FARMING SOIL LOSS TONS/ACRE	% REDUCTION IN SEDIMENT LOSS DUE TO CONTOUR FARMING SOIL LOSS	PHOSPHOROUS LOSS	NITROGEN LOSS	COMMENTS	REFERENCE
7. New York Iowa Georgia		5 3-5 4	Corn Corn Corn	8.9 7.6 18.3	3.1 3.6 7.6	65 55 60	65 55 60	- - -		Haith, 1979.
8. Iowa		12	Corn	25.0	10.0	60	-	-		Moldenhauer and Wischmeier, 1960.
9. Mississippi		5	Corn	-	-	72	-	-		Carter, et al., 1968.
10. -	-	-	Corn	-	-	-	-	-	Contour farming resulted in 17% increase in farming costs.	Stallinger, 1945.
-	-	-	Soybeans	-	-	-	-	-	Contour farming resulted in 14% increase in farming costs.	
11. Colorado		2-8	-	-	-	40-60	-	-	Contour farming resulted in 3 to 5% increase in farming costs.	Toups Corp., 1977
12. -	-	-	Corn	-	-	-	-	-	Contour farming resulted in 3 to 4% increase in farming costs.	Smith, et al., 1979.
13. -	-	-	-	-	-	50	40	-		Bos, 1983.
14. New York	-	-	Roto Crops	3.0	2.3	24	28	-	Contour farming resulted in 5% increase in farming costs.	Quinn, et al., 1984.

TABLE A-1 (Contd) DATA SUMMARY: REDUCTION IN SEDIMENT LOSS BY COVER CROPS/GRASSED WATERWAYS Page # 10

STUDY NAME/ LOCATION	TOTAL STUDY AREA, ACRES	GRADE OF SLOPE %	UNCOVERED/CONVENTIONAL CROPPING		COVER CROP		% REDUCTION IN POLLUTANT LOADS DUE TO COVER CROP SOIL LOSS-TONS/ACRE	COMMENTS	REFERENCE
			CROP	SOIL LOSS TONS/ACRE	SOIL LOSS TONS/ACRE	COVER TYPE			
1. Madison, South Dakota	0.02	5.8	Corn	2.68	1.63	Mulch	39	Mulch cover resulted in 10.8% or 6.3 bu/acre increase in crop yield.	Onstad, 1972
2. North Carolina	-	-	-	-	-	Grass	-	Grass cover resulted in $60/acre increase in farming cost and $1,200/acre in investment for farming.	Humenik, et al., 1982.
3. W. Tennessee Watershed	-	-	-	34.3	12.9	Grass	62		Foster, et al., 1978.
Piedmont Watershed	-	-	-	6.9	2.4	Grass	65		
4. Michigan	-	-	-	-	-	Grass	-	Grass cover resulted in $60/acre increase in farming cost or $2,200/acre in investment for farming.	Clark, 1985.
5. -	-	-	-	-	-	Grass	70		Bos, 1983.
6. -	-	-	-	-	-	Grass	60-80		International Joint Comm., 1983.
7. -	-	-	-	-	-	Grass	5-40		EPA, 1984.
8. N.W. Ohio	-	-	-	-	-	Grass	70	Grass cover resulted in $3,000/acre in investment costs for farming.	Logan & Forster, 1982.

TABLE A-3 (Cont'd) DATA SUMMARY: REDUCTION IN SEDIMENT LOSS BY COVER CROPS/GRASSED WATERWAYS

STUDY NAME/ LOCATION	TOTAL STUDY AREA, ACRES	GRADE OF SLOPE %	UNCOVERED/CONVENTIONAL CROPPING		COVER CROP		% REDUCTION IN POLLUTANT LOADS DUE TO COVER CROP SOIL LOSS-TONS/ACRE	COMMENTS	REFERENCE
			CROP	SOIL LOSS TONS/ACRE	SOIL LOSS TONS/ACRE	COVER TYPE			
9. Indiana	-	-	-	-	-	Grass	-	Grass cover resulted in $1,200/acre in investment costs for farming.	Lake & Morrison, 1977.
10. Lake Erie	-	-	-	-	-	Grass	-		Corps of Engineers, 1983.

TABLE A-4 DATA SUMMARY: REDUCTION IN NUTRIENTS LOSS BY CROP ROTATION

STUDY NAME/ LOCATION	TOTAL AREA ACRES	GRADE SLOPE Percent	CONVENTIONAL CROP ROTATION			IMPROVED CROP ROTATION (ICR)			% REDUCTION IN LOSS DUE TO (CR)		COMMENTS	REFERENCES
			CROP	P LOSS LBS./ ACRE	N LOSS LBS./ ACRE	CROP	P LOSS LBS./ ACRE	N LOSS LBS./ ACRE	P	N		
1. Wisconsin	-	3	Corn-Oats.	0.80	-	Corn-Oats (2 yr. hay)	0.19	-	76	-	Silt loam soil.	Massey et al., (1953).
	-	11	"	2.56	-		0.64	-	75	-	-	-
	-	20	Corn-Oats-(4 yr.-hay).	0.66	-	Corn-(5 yr. hay).	0.11	-	87	-	-	-
2. Georgia	-	3	Rye-Peanut.	0.07	-	Rye-Corn-Oats.	0.05	-	29	-	Sandy loam soil.	Thomas et al., (1968).
	-	3	"	0.07	-	Corn	0.02	-	73	-	-	-
	-	3	"	0.07	-	Oats-Rye.	0.02	-	73	-	-	-
3. W. Central Minnesota	-	6	Fallow.	0.35	-	Corn continuous.	0.13	-	62	-	loam soil.	Timmons , 1973
	-	6	Fallow.	0.35	-	Corn-Rotation.	0.09	-	75	-	-	-
		6	Corn-Rotation.	0.09	-	Oats-Rotation.	0.05	-	45	-	-	-
4. Mississippi	-	5	Soy-beans. "	0.99	0.86	Soy-beans-Wheat.	0.05	0.09	95	89	-	McDowell & McGregor (1980).
	-	-	"	0.99	0.86	Soy-Corn.	1.28	2.99	-29	-246	-	-
	-	-	"	0.00	0.86	Corn-Soy-beans.	1.68	10.44	-69	-1113	-	-
5. Minnesota	-	-	Continuous corn.	0.50	-	Corn-Oats-Hay.	0.02	-	96	-		Holt (1970)

TABLE A-4 DATA SUMMARY: REDUCTION IN NUTRIENTS LOSS BY CROP ROTATION

	STUDY NAME/ LOCATION	TOTAL AREA ACRES	GRADE SLOPE	CONVENTIONAL CROP ROTATION			IMPROVED CROP ROTATION (ICR)			% REDUCTION IN LOSS DUE TO (CR)		COMMENTS	REFERENCES
				CROP	P LOSS LBS./ ACRE	N LOSS LBS./ ACRE	CROP	P LOSS LBS./ACRE	N LOSS LBS./ACRE	P	N		
6	North Carolina	-	-	Continuous corn	-	20.8	Corn Rotation	-	12.5	-	40	In continuous 112 kg N/ha/yr. In rotation 56 kg N/ha.	Burwell et al., (1975).
7	-	-	-	Corn-Bean-Wheat	-	5.72	Corn-Bean-Wheat with cover crop.	-	1.5	-	74	-	Klausner et al., (1974).

TABLE A-1 (Cont'd) DATA SUMMARY: REDUCTION IN NUTRIENTS LOSS BY CONSERVATION TILLAGE/OTHERS

STUDY NAME/ LOCATION	TOTAL AREA, ACRES	GRADE/ SLOPE %	CONVENTIONAL TILLAGE			CONSERVATION TILLAGE (CT)			% REDUCTION IN LOSS DUE TO C.T.		COMMENTS	REFERENCES
			CROP	P LOSS LBS./ ACRE	N LOSS LBS./ ACRE	PRACTICE	P LOSS LBS./ ACRE	N LOSS LBS./ ACRE	P	N		
1 Lafayette, Indiana	-	2.5	Corn	2.52	-	Contour planting.	0.76	-	70	-	In conservation tillage high fertilizer levels were used.	White & Plate, 1979
	-	2.5	Wheat	0.72	-		0.43	-	59	-		
	-	2.5	Soy-beans	3.36	-	"	1.70	-	49	-		
2 Coshocton, Ohio	-	-	Corn	9.01	-	Contour planting.	2.74	-	70	-	In conservation tillage higher P levels were used.	White & Plate, 1979
	-	-	Wheat	1.17	-		0.35	-	70	-		
3 Lafayette, Indiana	-	8.2-12.4	Corn	7.07	19.85	Till plant-ing.	3.81	28.56	46	-43	-	
	-	"	"	7.07	19.85	Chisel plant.	3.24	3.24	73	84	-	Romken et al., 1973.
	-	"	"	7.07	19.85	Coulter.	7.37	35.40	-4	-78	-	
4 Mississippi	-	5	Soy-beans	14.08	27.28	No till.	1.15	0.86	92	97	-	McDowell & McGregor , 1980
5 New York	-	-	-	29.04	-	No till.	13.2	-	55	-	Model output using field data.	Haith and Loehr ,1979
6 Iowa	-	-	-	20.2	-	No till.	15.0	-	36	-		
7 Georgia	-	-	-	15.0	-	No till.	8.8	-	42	-	-	-
-	-	-	-	7.30	-	No till.	0.35	-	96	-	-	-
-	-	-	-	1.06	-	No till.	1.14	-	-7	-	" for 1970	Schwab et al., (1973).
-	-	-	-	34.21	-	No till.	9.6	-	72	-	" for 1971 values estimated from graph.	-
	-	-	-	1.67	-	No till.	0.28	-	83	-	-	Johnson et al., 1979. Logan 1981 .

Table 1 (App. B). Universal Soil Loss Equation (USLE)

Detailed descriptions of this equation and application methodology can be found in various studies (Wischmeir, 1959; Wischmeir and Smith, 1958; Moldenhaur, and Wischmeir, 1960). The general form of the improved equation is as follows:

$$A = R\,K\,L\,S\,C\,P$$

where:

A = the computed soil loss in tons per acre;

R = rainfall factor, designed to account for storm energy and intensity

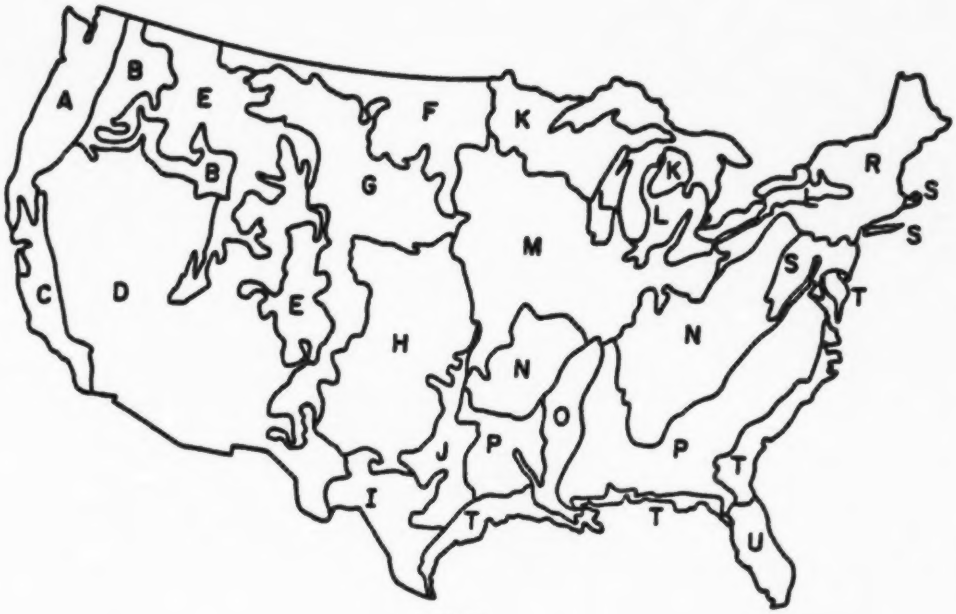
K = soil erodibility factor, average soil loss per acre per unit of R above from a specific soil on a unit plot of 72.6 feet length with a slope;

L = slope length factor, the ratio of soil loss from a specific slope to that from a 72.6-foot slope of similar characteristics;

S = is the slope steepness factor, relating to soil loss from a specific slope to that from a 9% slope;

C = cropping management factor, a ratio of soil loss from a field under one set of conditions to that from a field under fallow conditions;

P = erosion control practice factor, comparing the soil loss from contouring, strip cropping, and other structural control methods to that of up and down slope, straight-row farming.



LEGEND

A	Northwestern Forest, Forage and Specialty Crop Region
B	Northwestern Wheat and Range Region
C	California Subtropical Fruit, Truck and Specialty Crop Region
D	Western Range and Irrigated Region
E	Rocky Mountain Range and Forest Region
F	Northern Great Plains Spring Wheat Region
G	Western Great Plains Range and Irrigated Region
H	Central Great Plains Winter Wheat and Range Region
I	Southwest Plateaus and Plains Range and Cotton Region
J	Southwestern Prairies Cotton and Forage Region
K	Northern Lake States Forest and Forage Region
L	Lake States Fruit, Truck and Dairy Region
M	Central Feed Grains and Livestock Region
N	East and Central Farming and Forest Region
O	Mississippi Delta Cotton and Feed Grains Region
P	South Atlantic and Gulf Slope Cash Crops, Forest and Livestock Region
R	Northeastern Forage and Forest Region
S	Northern Atlantic Slope Diversified Farming Region
T	Atlantic and Gulf Coast Lowland Forest and Crop Region
U	Florida Subtropical Fruit, Truck Crop and Range Region

Figure 3. Land Resource Regions